

**Semi Automatic Construction Progress Measurement
Using a Combination of CAD Modelling, Photogrammetry
and Construction Knowledge**

By

Turker Bayrak

Submitted for the degree of Doctor of Philosophy

Heriot-Watt University
SCHOOL OF THE BUILT ENVIRONMENT

June 2008

The copyright in this thesis is owned by the author. Any quotation from the thesis or use of any of the information contained in it must acknowledge this thesis as the source of the quotation or information.

Abstract

Project managers are lacking up-to-date information about the current stage of the work on the site and they are unable to take corrective measures for the planning variations promptly. It is proposed that the method created within this thesis will reduce this problem greatly by supplying project managers with the data they need to understand schedule and cost variances as early as they occur. This gives them the power to step in and act in good time against the problems by identifying the reasons of the variations much earlier. This thesis is one of the attempts within academia about integrating computer based solutions to monitor and visualise construction progress.

Photogrammetric measurements offer reliable results at the cost of more human intervention. This approach offers the possibility of using a hand held camera as a measurement tool. This method also offers complete independence from reliance on the planning and design stage information. Hence, it can be used to re-evaluate, or monitor changes during the project life-cycle.

Visible physical body of a superstructure level reinforced concrete frame structure consists of walls, floors, beams, and columns. The building regulations and local construction traditions impose the types and the shapes of these structural elements. The manufacturing industry produces building materials such as bricks and floor blocks in standard sizes. Therefore, it can be seen that knowledge about the design criteria of structural elements or the standard sizes of materials available on the market for construction can be used to create 3D models of building components.

A Visual Basic for Applications (VBA) code was created to support these theories and presented in this thesis. The code then was tested and proven to be useful. After comparing the manual measurement results against the outcomes of the case study done for testing the proposed model, it has been revealed that the proposed model can produce 3D model of construction with accurate sizes within similar mistake margins which can be achieved manually.

Dedication

To

My Family

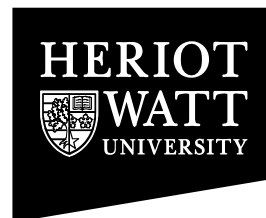
I dedicate this thesis in particular, to my mother, **Bulut**, father, **Osman** and my sister **Burcu** for their constant encouragement and patience. This research wouldn't be possible without their support.

Acknowledgement

I would like to take this opportunity to express my heartfelt thanks to my supervisor Ammar Kaka for his support and excellent directions he has given. I am grateful for his wise, friendly, skilful and professional research guidance.

I am also grateful to my friends Martin Livingston, David Bartlett, and Harriet Waugh for reading and correcting my thesis. Thank you for your efforts and help.

ACADEMIC REGISTRY
Research Thesis Submission



Name:	Turker Bayrak		
School/PGI:	School of the Built Environment		
Version: <small>(i.e. First, Resubmission, Final)</small>	First	Degree Sought:	PhD

Declaration

In accordance with the appropriate regulations I hereby submit my thesis and I declare that:

- 1) the thesis embodies the results of my own work and has been composed by myself
- 2) where appropriate, I have made acknowledgement of the work of others and have made reference to work carried out in collaboration with other persons
- 3) the thesis is the correct version of the thesis for submission and is the same version as any electronic versions submitted*.
- 4) my thesis for the award referred to, deposited in the Heriot-Watt University Library, should be made available for loan or photocopying and be available via the Institutional Repository, subject to such conditions as the Librarian may require
- 5) I understand that as a student of the University I am required to abide by the Regulations of the University and to conform to its discipline.

* Please note that it is the responsibility of the candidate to ensure that the correct version of the thesis is submitted.

Signature of Candidate:		Date:	___.07.2008
-------------------------	--	-------	-------------

Submission

Submitted By <i>(name in capitals)</i> :	TURKER BAYRAK
Signature of Individual Submitting:	
Date Submitted:	___.07.2008

For Completion in Academic Registry

Received in the Academic Registry by <i>(name in capitals)</i> :			
Method of Submission <small><i>(Handed in to Academic Registry; posted through internal/external mail):</i></small>			
E-thesis Submitted			
Signature:		Date:	

Table of Contents

Table of Contents

Abstract	i
Dedication	ii
Acknowledgments	iii
Submission Form	iv
Table of Contents	v
List of Figures	xi
List of Images	xiii

Chapter 1: Introduction

1.1. Introduction.....	2
1.2. Problem Statement.....	2
1.3. Aims and Objectives.....	4
1.4. Primary Objectives.....	4
1.4.1. Helping to Introduce Computer-Based Automation to Construction Management	4
1.4.2. Finding a Reliable Source to Collect As-Built Data.....	5
1.4.3. Finding an Effective Method in Order to Collect Data.....	5
1.5. Secondary Objectives.....	5
1.5.1. Providing Visual Aid for Inexperienced Clients.....	5
1.5.2. Knowledge Management.....	6
1.6. Contribution of the Research.....	6
1.7. Limitations of the Research.....	7
1.8. Evaluation of the Model.....	8
1.9. Guide to the Thesis.....	9

Chapter 2: Previous and Ongoing Research in Construction IT

2.1. Introduction.....	14
2.2. nD Models, Virtual Reality Tools and Knowledge Based Systems.....	15
2.2.1. SPACE.....	15
2.2.2. ICON.....	18

Table of Contents

2.2.3. OSCON (a.k.a. OSCONCAD).....	19
2.2.4. ATLAS.....	23
2.2.5. VIRCON.....	25
2.3. Automated Data Capture from Construction Sites via Barcode System.....	29
2.4. GPS and GIS Integrated Construction Management.....	31
2.5. Photogrammetry Applications.....	33
2.5.1. Semi-automatic CAD based reconstruction of industrial installations.....	33
2.5.2. PhotoModeler.....	35
2.5.3. Desktop Digital Photogrammetry System (DDPS).....	36
2.5.4. REALVIZ.....	37
2.6. Terrestrial Laser Scanning Applications.....	38
2.7. Full Automation and Computer Vision.....	39
2.7.1. Automatic Progress Assessment on Construction Sites Using Computer Vision	39
2.8. Conclusions.....	42

Chapter 3: Current Progress Measurement and Planning Methods

3.1. Introduction.....	46
3.2. Gantt Charts, Network diagrams and Critical Path Analysis.....	47
3.2.1. Gantt Charts.....	47
3.2.2. Network Diagrams.....	49
3.3. Earned Value Analysis (EVA).....	52
3.4. S Curves.....	57
3.5. Line of Balance Technique.....	61
3.6. Cash Flow Calculations.....	62
3.7. Conclusions.....	63

Chapter 4: Related Problems in the Construction Industry and Main Motives

4.1. Introduction.....	66
4.2. The Inhospitable Nature of a Construction Site.....	67
4.3. Lack of Up to Date As-Built Information.....	70

Table of Contents

4.4.	Construction Conflicts, Reasons and Avoidance.....	72
4.5.	Low Performance of the Construction Industry.....	74
4.6.	Increasing Predictability in Construction.....	75
4.7.	Tackling with Islands of Automation.....	76
4.8.	Need for a Better Surveying Method for Existing Buildings.....	77
4.9.	Knowledge Management.....	79
4.10.	Conclusions.....	80

Chapter 5: Methodology

5.1.	Introduction.....	83
5.2.	Common Types of Research Methodologies Available for Construction....	83
5.3.	Qualitative vs. Quantitative.....	84
5.3.1.	Qualitative Research.....	85
5.3.2.	Quantitative Research.....	86
5.4.	Data Collection Method Adopted For the Thesis.....	87
5.5.	Conceptual Framework of the Model.....	89
5.6.	Experiments and the Hypothesis to Justify.....	91
5.7.	Ethical Considerations.....	95
5.8.	Strengths of the Method Used.....	97
5.9.	Limitations of the Method Used.....	99
5.10.	Conclusions.....	100

Chapter 6: Extracting 3D Data from Digital Images

6.1.	Introduction.....	103
6.2.	Camera Models.....	104
6.2.1.	The Perspective Camera Model.....	104
6.2.2.	The Weak Perspective Camera Model.....	106
6.3.	Camera Parameters.....	106
6.3.1.	Extrinsic Parameters.....	106
6.3.2.	Intrinsic Parameters.....	108
6.4.	Taking Measurements from Images.....	109

Table of Contents

6.4.1. Benefits of Photogrammetry Based Method.....	117
6.4.2. Problems with the Photogrammetry Based Method.....	117
6.5. Conclusions.....	118

Chapter 7: Construction Knowledge Used in this Research

7.1. Introduction.....	121
7.2. Structural Columns.....	123
7.2.1. Rectangular Columns.....	123
7.2.2. Round Columns.....	126
7.3. Beams.....	126
7.3.1. Wider Beams.....	127
7.3.2. Regular Beams.....	129
7.4. Floors.....	131
7.4.1. Hollow Tile Floor Type.....	131
7.4.2. Regular Floors.....	132
7.5. Walls.....	132
7.5.1. Red Blocks.....	132
7.5.2. Autoclaved Aerated Block Walls.....	134
7.6. Conclusions.....	134

Chapter 8: Proposed Model Explained Using a Case Study

8.1. Introduction.....	136
8.2. Loading the Macro.....	137
8.3. Running the Macro.....	138
8.4. Module Level Events.....	140
8.5. The Excel Sheet.....	140
8.6. “Main Controls” Control Box.....	141
8.7. View Controls.....	142
8.7.1. 3D Building Model View Button.....	143
8.7.2. Digital Image View Button.....	144
8.7.3. Preview Button.....	145
8.8. Component Editor or “Shape Building Component” Functions.....	146

Table of Contents

8.8.1. Leave Trace.....	147
8.8.2. Abs Distance.....	148
8.8.3. Cut Horizontal.....	149
8.8.4. Cut Vertical (X).....	152
8.8.5. Cut Vertical (Y).....	152
8.8.6. Subtract Interference.....	153
8.8.7. Clean Up.....	154
8.8.8. Undo.....	154
8.8.9. Rotate 3D.....	155
8.8.10. Move.....	155
8.8.11. Copy.....	155
8.9. Add Building Component Functions.....	156
8.9.1. “Add Column” Tab.....	156
8.9.2. “Add Beam” Tab.....	158
8.9.3. “Add Slab” Tab.....	160
8.9.4. “Add Wall” Tab.....	162
8.10. “Send to Excel” Buttons.....	163
8.11. Conclusions.....	168

Chapter 9: Evaluation

9.1. Introduction.....	170
9.2. Outcomes versus Targets.....	170
9.2.1. Evaluation of the 3D Models Created.....	172
9.2.2. Evaluation of the Volumetric Calculations.....	173
9.2.3. Evaluation of the Spreadsheets.....	174
9.2.4. Data Format Conflicts, Data Re-entry and Data Losses Avoidance.....	176
9.3. Reactions and Comments from the Industry.....	178
9.3.1. Positive Reactions.....	178
9.3.2. Negative Reactions.....	179
9.4. Conclusions.....	179

Table of Contents

Chapter 10: Summary and Conclusions

10.1. Introduction.....	182
10.2. Executive Summary of the Thesis.....	182
10.3. Conclusions of This Research.....	185
10.3.1. Conclusion 1: Automation is needed in the Construction Industry.....	185
10.3.2. Conclusion 2: As-Built Data Must Be Collected Directly from Construction Sites.....	186
10.3.3. Conclusion 3: Method of Data Collection.....	186
10.3.4. Conclusion 4: Problems with Solely Photogrammetry Based Method.....	188
10.3.5. Conclusion 5: Improvements to the Model through Construction Knowledge	188
10.3.6. Results Gained.....	189
10.4. Contribution of This Research to the Knowledge.....	189
10.5. Recommendations for the Future Work.....	190
10.5.1. Introducing BIM to Progress Measurement.....	190
10.5.2. Linking the 4D Models with the Proposed Model.....	191
10.5.3. Integration of Further Construction Knowledge.....	191
10.5.4. Integration of Mobile Phone Technology.....	192

List of References.....	194
--------------------------------	------------

Appendix 1. VBA Code Used in the Application.....	207
--	------------

10.1. Module Level Codes.....	207
10.2. Sub-procedures.....	211

Appendix 2. CAD Drawings.....	245
--------------------------------------	------------

List of Figures

Figure 2.1: OSCON / OSCONCAD Architecture.....	20
Figure 2.2: An overall picture of applications integrated by OSCON.....	22
Figure 2.3: The ATLAS model hierarchy.....	24
Figure 2.4: Overall process of VIRCON database.....	26
Figure 2.5: Computer integration using bar code.....	30
Figure 2.6: Framework of the GPS and GIS Integration.....	32
Figure 2.7: Interactive alignment of a CAD model to an image.....	34
Figure 2.8: Garage door model.....	41
Figure 3.1: Gantt (bar) chart representation of a project.....	47
Figure 3.2: Network diagram with critical path.....	51
Figure 3.3: An example of an S-curve	57
Figure 3.4: Cumulative manpower consumed for electrical systems installation...	59
Figure 3.5: Earned value and performance measurement via s-curves.....	60
Figure 4.1: “Zazadin Caravansary”, Corolla door.....	78
Figure 5.1: Research Strategy.....	88
Figure 5.2: Framework of the model.....	90
Figure 6.1: The perspective camera model.....	105
Figure 6.2: The relation between camera and world coordinate frames.....	107
Figure 6.3: Camera Alignment Example 1.....	110
Figure 6.4: Camera Alignment Example 2.....	111
Figure 6.5: 3D Modelling with Photogrammetry 1.....	112
Figure 6.6: 3D Modelling with Photogrammetry 2.....	112
Figure 6.7: 3D Modelling with Photogrammetry 3 (a, b, c).....	115
Figure 6.8: 3D Modelling with Photogrammetry 4 (a. b).....	116

List of Figures

Figure 7.1: Main tectonic elements of Turkey.....	122
Figure 7.2: Letters representing the dimensional parameters of a column.....	125
Figure 7.3: Letters representing the dimensional parameters of a beam.....	129
Figure 7.4: Hollow-tile floor type.....	131
Figure 8.1: Load Project Menu.....	138
Figure 8.2: Macros chart.....	139
Figure 8.3: The top section of the Excel spreadsheet.....	141
Figure 8.4: “Main Controls” control box as the main user interface.....	142
Figure 8.5: “3D Building” view setting.....	144
Figure 8.6: “Digital Image” view setting.....	145
Figure 8.7: “Preview” view setting.....	146
Figure 8.8: Co-linearity principle.....	147
Figure 8.9: “Abs Distance” command	149
Figure 8.10: An example of a 200/800mm column.....	150
Figure 8.11: “Cut Horizontal” command.....	151
Figure 8.12: “Cut Vertically” command.....	153
Figure 8.13: “Subtract Intersection” command.....	154
Figure 8.14: “Rectangular Column” dropdown list.....	158
Figure 8.15: “Standard Beams” dropdown list.....	159
Figure 8.16: “Standard Slabs” dropdown list.....	161
Figure 8.17: The “Red Bricks” dropdown list.....	163
Figure 8.18: The 3D model of the project.....	165
Figure 8.19: The image used for the case study.....	166
Figure 8.20: Spreadsheet showing the BCWP.....	167
Figure 9.1: Inaccuracies of the proposed model.....	172
Figure 9.2: (a,b,c,d) Exporting quantities to Excel.....	175

List of Images

Image 4.1: Inhospitable and inaccessible nature of construction sites.....	67
Image 5.1: A summerhouse in Kusadasi.....	93
Image 5.2: Another summerhouse in Kusadasi.....	93
Image 7.1: Hollow-tile floor slab.....	128
Image 7.2: A villa	130
Image 7.3: A villa.....	133

Chapter 1: Introduction	2
1.1. <i>Introduction</i>	2
1.2. <i>Problem Statement</i>	2
1.3. <i>Aims and Objectives</i>	4
1.4. <i>Primary Objectives</i>	4
1.4.1. Helping to Introduce Computer-Based Automation to Construction Management	4
1.4.2. Finding a Reliable Source to Collect As-Built Data	5
1.4.3. Finding an Effective Method in Order to Collect Data	5
1.5. <i>Secondary Objectives</i>	5
1.5.1. Providing Visual Aid for Inexperienced Clients	5
1.5.2. Knowledge Management	6
1.6. <i>Contribution of the Research</i>	6
1.7. <i>Limitations of the Research</i>	7
1.8. <i>Evaluation of the Model</i>	8
1.9. <i>Guide to the Thesis</i>	9

Chapter 1: Introduction

1.1. Introduction

Construction progress measurement is an extremely critical task undertaken by both clients and construction industry professionals very carefully. A great deal of effort, time and money needs to be invested into these activities in order to obtain reliable data on time. Despite the efforts of the project team members given to these measurement activities, these calculations still remain a major source of construction conflicts.

This chapter introduces the thesis which reports on the outcome of research in the area of semi-automatic construction progress measurement, using a combination of CAD modelling, photogrammetry and construction knowledge.

The reasons for undertaking research in this area are discussed in this chapter. The topic of the research is explained and references made to introduce chapters and where they fit within the thesis structure. The aims and objectives of the thesis are also elaborated upon in this chapter.

1.2. Problem Statement

There is a lack of as-built data about progress on construction sites (Saidi, Lytle et al. 2003). The absence of real-time information handicaps managers' ability to monitor schedule, cost and other performance indicators, which reduces their ability to detect or manage the variability and uncertainty inherent in project activities (Howell 1999).

Measuring progress on-site is generally done by traditional surveying methods that are slow or may be inaccurate. Davidson and Skibniewski reported that with very few exceptions, construction activity is measured using traditional manual data collection, such as supervisors filling in timesheets for workers, collecting paper documentation like delivery notes, etc (Davidson and Skibniewski 1995). Data collected manually on

these sheets need to be re-entered to computer applications. As a result, double entries create unnecessary labour activity and cost. Some of the data collected on site using pen and paper based methods might never be entered into a computer and consequently, can be lost forever.

Construction sites are chaotic places, constantly exposed to the influence of numerous external and internal factors. While weather conditions, strikes, natural disasters or economic conditions can affect the construction progress, the complexity created by the nature of the work itself will also affect the progress on the site. These problems contribute to client dissatisfaction, cause schedule and cost variances, and create conflicts within project teams. Overall, the reputation of the industry is harmed, and the construction is seen as a risky endeavour by the investors.

The Egan report (Egan 1998) warned the industry about the communication problems between clients and contractors. Construction clients may or may not be experienced in building procurement. They can be unable to express what they need or expect from the project, and when they see the drawings produced by industry professionals, they do not always understand everything they see.

Industry and academia continually produce a variety of solutions to resolve the internal and external problems that create the difficulties of construction work. Computer integration applied to construction is one of the solutions commonly resorted to (Aouad, Betts et al. 1994).

On the one hand, new automation solutions help resolve individual aspects of the complexity on the site. On the other hand, these solutions are incompatible with each other; therefore they create the phenomenon called islands of automation (Hannus, Penttila et al. 1998). These islands of automation sort the information they produce with the data format they use, while these individual data formats are often not exchangeable by any other automation method.

Due to the nature of the construction industry, during the construction stage, data collection for knowledge and the storage of this data is difficult. There is a constant circulation of personnel. Whenever the need emerges, people are hired and at the end of the project duration they may get fired. Construction companies cannot learn enough from the experience gained by these people throughout the project duration when these people leave. A great deal of knowledge that can be re-used by the company in future contracts is lost when a project team is disbanded.

Therefore, the problems concerning this thesis are multi-dimensional. An automation based solution to reduce the cost and schedule variances of the construction projects can be helpful; however it can create more data exchange problems. A method that can produce the kind of data usable by other applications, easily understandable by clients from other industries is necessary. This method should be able to measure the progress on site and help to control cost and schedule variances.

1.3. Aims and Objectives

The aim of this research is to create a prototype computer application to address the gaps explained under the problem statement heading. The main objective is to improve construction progress measurement. The prototype created by the thesis is intended to calculate the financial worth of the progress on-site for interim payments.

1.4. Primary Objectives

The main objectives are categorised in the following sections.

1.4.1. Helping to Introduce Computer-Based Automation to Construction Management

The first objective is helping to introduce computer-based automation to construction management. The proposed model intends to address repetitive data entry and manual data collection issues explained under problem statement. The proposed application

must not create new data formats that can not be exchanged by other applications. The data produced by the proposed application must be exportable or exchangeable by other computer applications like Virtual Reality or various planning and scheduling software.

1.4.2. Finding a Reliable Source to Collect As-Built Data

Since there is a lack of up-to-date as-built data available for project managers, this data needs to be collected by means of an effective method. This research aims to evaluate various alternative sources data can be collected. The necessary data can be collected from construction sites as the project progresses, or it can be extracted from design and planning documents. This thesis aims to review literature in order to evaluate and compare various alternative data sources.

1.4.3. Finding an Effective Method in Order to Collect Data

Once a reliable source is found, there must be an effective method to collect this data. The research aims to first explore available methods. Once it finds an effective strategy in order to collect data, it aims to develop this method and report the results, so that the academia and industry can benefit from it.

1.5. Secondary Objectives

Secondary objectives are categorised in the following sections.

1.5.1. Providing Visual Aid for Inexperienced Clients

A secondary objective of the thesis is introducing visual support to construction documentation. Since the clients of the construction industry are not always experienced in the building procurement, or they are often unable to completely understand the construction documentation, the output of the model must be easy to understand. Results must be unambiguous and uncontroversial to avoid conflicts that are common

within construction project teams. Therefore one of the objectives of the application is to provide enough visual aid to the customer via 3D CAD models and digital photos.

1.5.2. Knowledge Management

Knowledge management is important to utilise the know-how that has been generated in previous contracts. Recording and re-using visual and numerical data about the previous construction endeavours can save money and time of construction industry members in future contracts. Therefore, the thesis also aims to improve and create knowledge management opportunities.

1.6. Contribution of the Research

Literature review reveals that (Arayici 2007), (Arayici and Hamilton 2005), (Trucco and Kaka 2004) one of the recent mainstream directions in computer integrated construction is focussed on construction progress measurement. But it was not always this way. Computer integrated construction became a common subject when building design and planning related software first started to emerge. Within a broad categorisation, it can be said that this research falls into the territory of computer integrated construction as a subject area.

As mentioned previously, these software solutions helped in resolving individual parts of the construction planning and design process rather than producing more integrated solutions. While this situation resulted in new varieties of data exchange problems, it also led the industry and academia to think about the integration aspect of the problem. This new situation produced the first generation of 4D and nD models alike. These solutions involved integrating the design information in 2D or 3D with planning data represented by bar charts or network diagrams.

The subject of this thesis is different from the above group of research. The data these applications target are generated during the pre-construction stage and therefore was subject to change during the course of actual construction activities. A new generation

of research area has emerged to address this problem. This new research area is concerned with progress monitoring and measurement. Academics are suggesting solutions regarding better ways the industry can assess the progress on-site in order to know the current status of construction. The main contribution of this research is also about construction progress measurement. Other researchers in this area use various levels of automated data collection strategies for progress measurement whilst this one proposes using digital images together with CAD models, photogrammetry and a construction knowledge base. The reasons for choosing these particular data collection methods can be found in the literature review chapter. A comprehensive review of the literature in computer integration to construction can be found in Chapter 2.

Other than the main contribution explained above, it can be argued that there are secondary contributions related to providing visual aid to construction documentation. Communication problems between inexperienced clients and construction industry professionals is well documented (Egan 1998). The industry is aware that communication problems can be overcome by the introduction of 3D computer based models and photography to construction documentation. 3D models and construction site photographs are increasingly being used by the industry for communication purposes or within the contract documentation for a variety of reasons. Contractors often attach digital images of the construction progress to their bills of quantities so that the clients can be convinced about the worth of the interim payments. Architects often use 3D models of their designs to show their client what they are buying before the financial commitment takes place. In fact, these models and digital images have greater potential in them than the construction industry professionals are currently benefiting from. The proposed model introduces these 3D models and digital images as the source of interim payment calculations. Therefore, the calculations are supported with plenty of visual material.

1.7. Limitations of the Research

The scope of the progress measurement activities proposed in this thesis is limited to the superstructure only. The measurement tools are capable of measuring the visible

construction components while the infrastructural or building services related works are not included as part of the project to be measured by the proposed method.

The method uses specific knowledge on construction and this knowledge is not universal between different countries. Therefore; the model is limited to the Turkish construction industry only. In order to apply the model to other countries, the knowledge base needs to be expended or customised to match the relevant countries construction technology and building regulations.

The type of construction used also affects the measurement method directly. For different building techniques, the same methods of measurement can be applied; however, the construction knowledge must be changed. This research is limited to reinforced concrete frame structures. The same strategy can be applied to the other type of building methods like steel frames or masonry walls.

The size and function of the building have an important effect on the way the structure is designed. For every different size and type of construction, there is the need to develop a relatively different set of construction knowledge base. Therefore, the research is constrained to villa type summer house buildings. The same logic however can be applied to other sizes and functions of building.

1.8. Evaluation of the Model

The method used to evaluate the proposed method is a case study. The proposed method is a progress measurement technique. The construction site of a Turkish Summer house was used as a case study in this research and the output of the measurement and reporting activities generated by the model was compared with the actual values. Such a comparison confirmed the accuracy and the practicality of the model. Some drawbacks or shortcomings of the model were also identified during the same experiment. The results and the experiment itself are detailed in chapter 8.

Since the proposed model has quantitative methodology, the main evaluation method is based on numerical comparison. Therefore, the evaluation chapter (Chapter 9) contains numerical comparisons of the calculations created by the model and the results of the on-site measurements obtained manually.

Evaluation of the proposed method also involves non-numerical issues such as practicality, usefulness or feasibility aspects of the model. To undertake a comparison without resorting to numerical data, practicality or usefulness aspects of the method were discussed by industry representatives. Favourable results have been gained from the informal interviews.

1.9. Guide to the Thesis

The thesis consists of 10 chapters. The first chapter is an introduction chapter. In this chapter a general definition of the research is introduced. The current research directions within the subject area are outlined together with the specific references of the thesis.

Chapter 2 is the literature review chapter. The majority of the prominent work in the area of Computer Integrated Construction is examined here. Different directions in the progress measurement area are critically examined to determine and justify the objectives chosen in this thesis. This chapter is aimed at classifying and analysing the major research projects undertaken by academia within recent years. Before going into the various research attempts, the chapter first explains why academia is so concerned about further computer integration and what is meant by the term “Islands of Automation”. The chapter then goes into the matter of how academia suggests different solutions for the problems defined under four main headings, “nD Models, Virtual Reality Tools and Knowledge Based Systems”, “Photogrammetry Applications”, “Terrestrial Laser Scanning Applications”, and “Full Automation”.

Each research project named within the chapter is analysed further from aspects like its relevance to the main subject, solutions proposed by the researchers, achievements they brought, failings and shortcomings.

Chapter 3 reviews current progress measurement techniques that fall outside of “Computer Integrated Construction”. The relevance of these techniques and how they can benefit from the proposed research methodology are explained.

This chapter is an analysis of available solutions for project managers in a Construction Progress Monitoring and Measuring context. The chapter aims to review why the analysis tools are being used, and where they can be improved within the context of the proposed research. Various automation tools on the market are given as examples. The areas reviewed are, Gantt Charts, Network diagrams and Critical Path Analysis, Earned Value Analysis (EVA), Cash Flow and S Curves.

Chapter 4 introduces the main motivation sources and the reasons leading the researcher to this area. Aims and objectives of the research are also detailed. This chapter mainly explains the motives that led researchers to find out better methods to collect data from construction sites. The hostile nature of construction sites and the direct implications of this nature on project management disciplines are discussed. As one of the big problems project managers face today, lack of up to date as-built information is analysed. Ideas are supported with academic publications where appropriate. Construction conflicts and how they cause financial problems on project stakeholders are mentioned. How these conflicts can be avoided or resolved is discussed within the computer vision and construction automation context. Construction industry clients are seeing the industry as unpredictable and underachieving. This problem and how it can be addressed by Construction Automation is explained. Necessary examples are given from previous academic work when available.

Chapter 5 explains the methodology used in this research. The limitations and the strengths of the method are elaborated upon. This chapter includes detailed subjects covered by the research. Procedures and objectives are also explained. This chapter also

introduces the strengths and weaknesses of the research outcomes in this thesis. Ethical considerations were also discussed within the limits of this chapter. Classification of the methods used in this study also was made from “quantitative versus qualitative” aspects.

Chapter 6 details the fundamental geometric knowledge used by the photogrammetry and computer vision branches. This is the mathematical and geometrical information employed by the proposed method in order to take measurements from the images. One of the main bases of this research is the photogrammetry knowledge. The subjects elaborated upon in this chapter are the importance of the camera models, how they can be classified or defined.

The chapter concludes by detailing how a camera model can help in revealing the dimensions of the items in the image or how images are geometrically related to the objects within the scene. This information is fundamentally important for the theory behind this research.

Chapter 7 is about how construction knowledge can be used to reduce the problems and impracticalities created by the photogrammetry based method. Construction knowledge is another main base of this research. Building regulations, material standards, physical limitations of the materials or manufacturing industry standards are all contributing to the physical design and shape of a building component. This chapter explains how this knowledge can be used in favour of automated construction progress measurement.

The eighth chapter elaborates on the experiment used to justify the theory of this thesis. Another base of the research is CAD modelling. Using the VBA application, a 3D model of the construction is created out of digital photos. A spreadsheet of bills of quantities is produced out of the 3D CAD model by means of automation, showing the current value of the works that have been achieved on the site.

The ninth chapter is the evaluation chapter. In this chapter the performance and accuracy of the proposed model is evaluated by comparing the numerical results with on-site manual measurements. The chapter also analyses the results of informal

interviews undertaken with the industry representatives from both clients and contractors side in order to evaluate the usefulness of the method.

The tenth chapter concludes the thesis. The outcomes of the research and the additional insight gained are introduced. An executive summary of the thesis can also be found in this chapter.

Chapter 2: Previous and Ongoing Research in Construction IT**14**

2.1.	<i>Introduction</i>	14
2.2.	<i>nD Models, Virtual Reality Tools and Knowledge Based Systems</i>	15
2.2.1.	SPACE	15
2.2.2.	ICON	18
2.2.3.	OSCON (a.k.a. OSCONCAD)	19
2.2.4.	ATLAS	23
2.2.5.	VIRCON	25
2.3.	<i>Automated Data Capture from Construction Sites via Barcode System</i>	29
2.4.	<i>GPS and GIS Integrated Construction Management</i>	31
2.5.	<i>Photogrammetry Applications</i>	33
2.5.1.	Semi-automatic CAD based reconstruction of industrial installations	33
2.5.2.	PhotoModeler	35
2.5.3.	Desktop Digital Photogrammetry System (DDPS)	36
2.5.4.	REALVIZ	37
2.6.	<i>Terrestrial Laser Scanning Applications</i>	38
2.7.	<i>Full Automation and Computer Vision</i>	39
2.7.1.	Automatic Progress Assessment on Construction Sites Using Computer Vision	39
2.8.	<i>Conclusions</i>	42

Chapter 2: Previous and Ongoing Research in Construction IT

2.1. Introduction

In the UK economy, ten percent of the Gross Domestic Product is generated by the construction industry (Egan 1998). Information Technology is recognised as one way of improving the industry's efficiency. This has been recognised by governments and academia through the growing number of research projects and investments in this area.

The construction industry is perceived to be underachieving by its clients. Projects are widely seen as unpredictable in terms of delivery on time, within budget and to the standards of quality expected. Although tremendous effort is spent on monitoring the work on the construction site, the construction industry is still failing to satisfy more than a third of major clients (Egan 1998). Partial or preferably full automation of the construction process is currently seen as the way forward for resolving these problems.

Another problem is that the construction industry is fragmented in nature. The design process is separated from the construction process and the lack of essential involvement of designers, estimators and other construction professionals exacerbates this fragmentation. In the past, researchers have proposed IT for providing numerous decision support systems for the professionals involved in the industry. These systems have created what is regarded as "islands of automation" and are far from achieving an acceptable level of integration across disciplines and across the design and construction process (Kartam 1994). Linking those "islands of automation" together is a challenge both academia and industry are currently trying to fulfil.

There is an increasing number of research projects being undertaken in academia to achieve further integration of computers in to the construction industry. While some researchers are trying to improve the communication links among the construction industry stakeholders via network technologies or creating new data exchange methods, others are focusing on increasing the quality of design and planning stage activities. A

new area of research is also emerging which focuses on construction progress monitoring and in particular the time, cost and quality aspects of the project. The subject topic of this thesis falls into this last category.

2.2. nD Models, Virtual Reality Tools and Knowledge Based Systems

An nD model has been defined as “an extension of the building information model, which incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility” (Marshall-Ponting and Aouad 2004).

Common properties of nD models are, to do with using design and planning data together and linking them via an interface. The design data comes from a 3D CAD model or 2D CAD drawings, while individual construction activities within the planning data is linked to these 3D building components by means of a software, a virtual reality (VR) tool is commonly being used for the visual presentations of the models. A number of successful examples from this category are described under the following headings.

2.2.1. SPACE

Faraj and Alshawhi define the SPACE (Simultaneous Prototyping for an Integrated Construction Environment) system they developed as:

SPACE is a rapid prototyping environment which supports a subset of a construction project life cycle. Its main objective is to develop a future intelligent integrated design and construction system for the civil and building domain through which a number of solutions can be generated and analyzed. This is accomplished through the use of a comprehensive project data model capable of supporting a range of applications. The data model consists of an independent data model and application specific data models. The research concentrates on establishing a project data infrastructure and tools for managing the information exchange that occurs during a project life cycle, with

emphasis on the design, site layout and construction planning, cost estimation and maintenance applications (Faraj and Alshawhi 1999).

This model relies on attributes entered on 3D CAD elements manually at the end of the design stage. These attributes are later used for various construction related software packages to produce project estimate, interim payments, facility management and maintenance forecasting applications or VR visualizations. These applications are explained as follows:

CAPE (Putra 1998) (Construction Application Protocol for Data Transfer) is the element recognition and design analysis module of SPACE. The aim of CAPE is to establish, generate, control and store comprehensive project specific information, representing the generic multiple designers' views of a building model for reinforced concrete office buildings. The information generated by CAPE includes most of the physical building information such as project specific information and details of building elements, i.e. geometry, topological, location etc. This model acts as the main distributor of project's specific information to the other data models.

The SPECIFICATION (Alshawhi and Underwood 1996) module produces the specification of each of the building elements which are retrieved from databases of standard components/materials. These databases have been developed based on WESSEX's cost database. The specification describes the building element component such as brick or concrete, inner or outer wall, insulation type, mortar mixes, etc. Each specification is only created once in the SPECIFICATION's module, which is later referred to by other building elements.

CONPLAN (Hassan 1997) is the construction planning and constructability analysis module of the SPACE project. The application uses design and estimating data from the CAPE and EVALUATOR modules to generate construction plans in three levels of details, i.e. detailed executive and master plan (Putra 1998).

EVALUATOR (Alshawhi and Underwood 1996) is “Project Estimate and Interim Valuation Generation in an Integrated Environment”. Its main purposes is to produce project estimates in the form of elemental BQ and to generate monthly interim valuation certificates from the construction plan. EVALUATOR uses virtual reality as an interfacing tool to simulate the project based on the valuation period (Hassan 1997).

INTESITE (Intelligent Site Layout Planning) (Alshawhi and Suliman 1995) is A dynamic site layout production tool for a given design and construction plan which complies with standard regulations, safety, and productivity rules and to display and manipulate information in any graphical environment with suitable interface (CAD or VR).

The aims of CONVERT (Construction Virtual Environment) (Alshawhi and Faraj 1995) is to support applications that perform functions within the project life cycle by mapping views of these applications to a virtual environment. The application generates virtual reality models for the design elements created by AutoCAD/AEC in real time. CONVERT also enables the virtual objects to be interrogated.

SPACE and its sub-research products are useful utilities to exploit available design and planning data. Multidisciplinary interface of the application serves the overall aim of “integration in construction IT” purpose very well, however the overall reliance on the data available in the design and planning stage is the main weakness of the system. The output of the system is always about what was planned and designed, rather than what really happened on the site. The system requires the input of schedule and cost variances as they occur. Planning information needs to be overwritten to reflect the usual changes of cost or time aspects of the construction project. SPACE was a breakthrough in prototyping; however it does not offer a technique to create information. It is a set of methods to use information already created in the design stage more effectively and accurately.

2.2.2. ICON

ICON is a research project developed within the University of Salford, UK (Aouad, Kirkham et al. 1995). ICON attempts to provide a framework of information into which the modelling of construction management information fits. This methodology is based on the coupling of two powerful information modelling and analysis techniques namely Information Engineering and Object Oriented Analysis and Design with the assistance of an object oriented CASE (Computer Aided Software/Systems Engineering) tool which automates the production of information models. The Information Engineering method was used for the strategic planning of information using activity decomposition/activity hierarchy whilst the Object Oriented Analysis and Design approach was performed at the analysis, design and implementation stages due to the incorporation of the notion of information perspectives. An Object Oriented CASE tool (Ptech) is being used to assist in producing the various information models required by the construction management disciplines and to generate executable computer code from these models.

The ICON research work followed a top-down approach which aims at producing integrated product and process models for the various ‘perspectives’ of the stages involved in the life cycle of a project. High level objects have been defined to reflect the main stages of a construction project such as Defining, Procuring, Designing, Constructing, Commissioning and Maintaining. Each of these high level objects are further decomposed to reflect the product data model thus representing detailed levels and the concerned processes such as construction planning, estimating, etc. (Aouad, Betts et al. 1994)

ICON uses a method that involves separating the construction into several object oriented models, each describing the information needed to support a single well-defined activity (Cooper, Aouad et al. 1993). These small manageable information models are referred to as “Perspectives”. Object oriented analysis techniques are used to build and integrate the perspectives into a single multi-faceted information model for a certain domain such as construction planning, conceptual design, spatial design, physical design, structural design, determine procurement systems etc. (Putra 1998).

However, lack of data standardisation has proved to be a major obstacle for these and many other computer-integrated construction research efforts (Dawood, Akinsola et al. 2002). Like many computer integrated construction projects of its time, the ICON project also couldn't be adopted by the industry and remained as an academic exercise.

2.2.3. OSCON (a.k.a. OSCONCAD)

OSCON (Open Systems for Construction) is a two year funded project which is mainly aimed at developing demonstrators for applications such as architectural design, cost estimating, and planning integrated within a central database. The main contribution is the development of a set of interfaces between an object oriented database (object store) and commercial products such as AutoCAD 13, Superproject, and Netscape navigator in order to allow the sharing of information and to allow for more user friendly interfaces (Aouad, Child et al. 1997).

The OSCONCAD Architecture adopts the Client/Server approach as shown in figure 2.1. The server is composed of the OSCONCAD objects. Two kinds of objects are provided:

1. Objects that reflect the database schema of the OSCONCAD architectural design model where instances of the design component are stored,
2. A set of Abstract Design Classes, which provide abstractions that the design model classes can use to render themselves in a given display environment (Marir, Aouad et al. 1998).

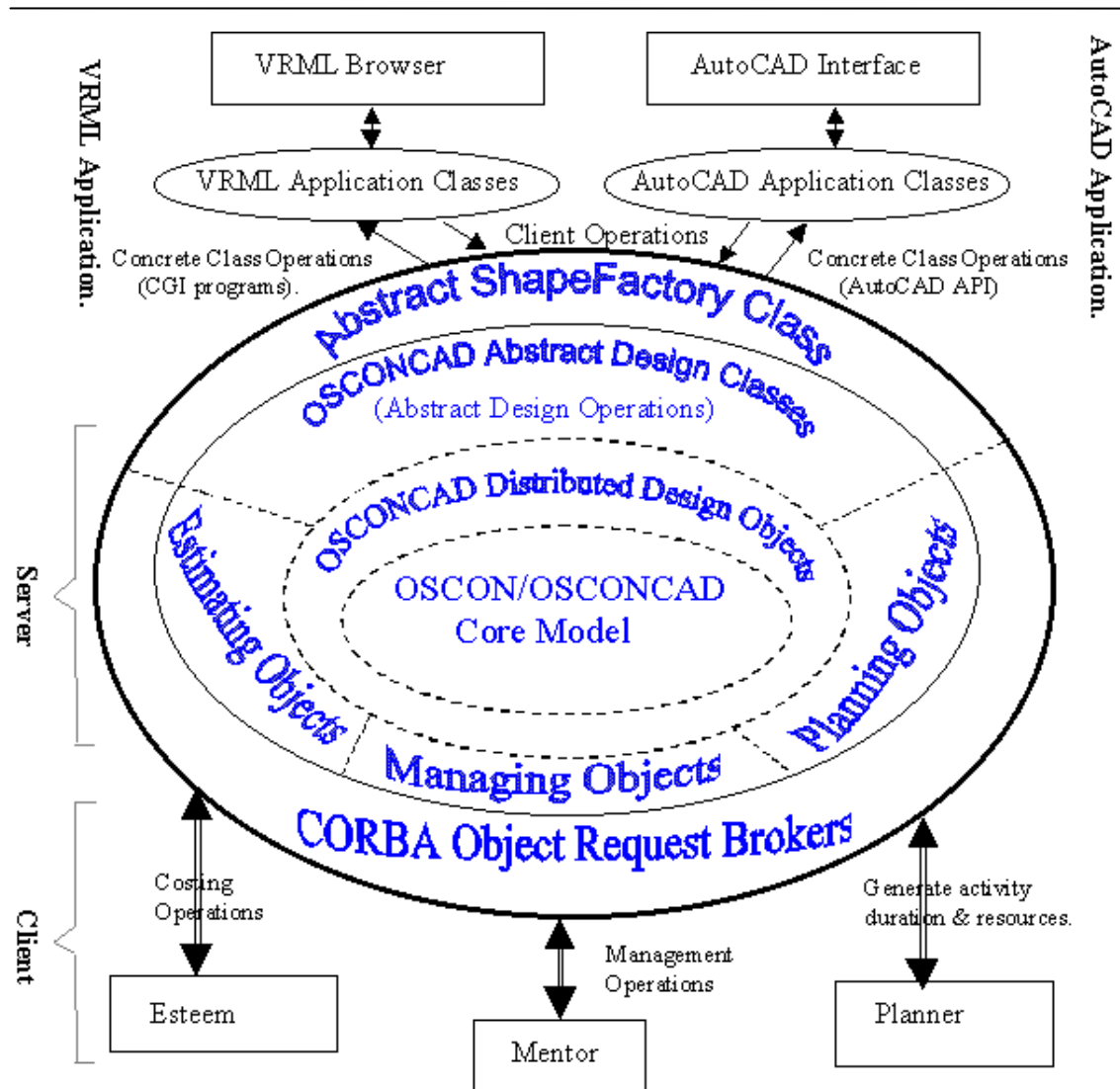


Figure 2.1: OSCON / OSCONCAD Architecture (Marir, Aouad et al. 1998)

OSCON integrates design software (AutoCAD 13) with an estimating package (Esteem), a planning application (CA-Superproject), management application and a Virtual Reality Utility (VRML) tools all together.

Projects are designed in 2D or 3D using AutoCAD. The design objects created by the OSCON can be foundations, slabs, columns, beams, walls, roofs doors or windows.

The cost estimating tool Esteem looks like a spread sheet which is also easy to use. This utility can be used as a stand alone tool or integrated with AutoCAD. A library of standard work items and standard resources which can be company specific is used to identify work items and recourses for a project (Aouad, Child et al. 1997). The user can

experiment with the design model and see the cost changes within the estimating package.

Planning tool CA-Superproject is used to import construction operations identified within the database. The activity duration and resources should be read from the database and passed to the planning software (Aouad, Child et al. 1997). The links between operations were left to the decision of the operator to avoid making the OSCON system too rigid.

The Virtual Reality application VRML reads the information from AutoCAD and visualises it in a virtual reality environment. This utility is mainly used for interrogating the integrated database remotely over the internet in order to allow practitioners within the construction industry better access to the OSCON integrated database.

Project management utility allows the person in charge of the project to control communications within the project team, freeze or unfreeze the design process or limit access or manipulation to the participants.

Chapter 2

Previous and Ongoing Research in Construction IT

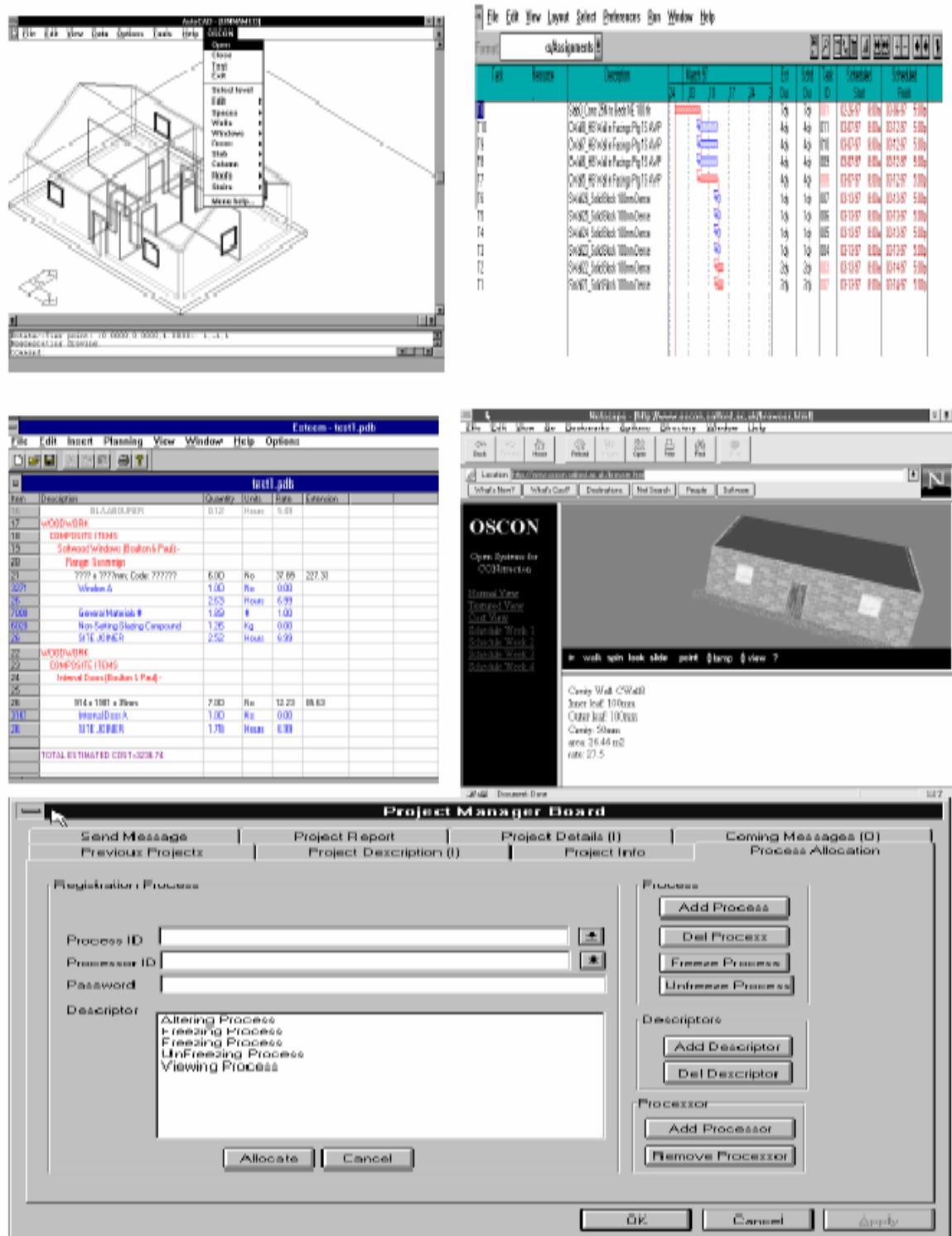


Figure 2.2: An overall picture of applications integrated by OSCON (Aouad, Child et al. 1997)

In addition to the functions above, a procurement selection application added to the OSCON. This application helps the operators of the project to decide about the suitable procurement approach by evaluating criteria like time, cost, quality, complexity, price certainty or competition to suggest the suitable procurement method for the project.

The OSCON project and the prototype developed by the OSCON team achieved great potential in computer integration for the construction industry. Integrating various software packages together under the OSCON project was a successful approach to reduce the gaps among the so called “Islands of Automation” the industry is experiencing today.

As a limitation, it can be argued that the OSCON project is too focused on the pre-construction stages of project life-cycle. It is a design and planning stage tool with very little use when the construction activities actually start. Being able to re-plan and re-schedule construction activities due to the changes that occur during the construction process requires more input than what was available in the planning stage. Monitoring the actual construction process to keep the project on track in terms of time and cost is neither automated nor even considered in these kinds of applications. Data used in the model comes from conventional design stage products like 2D/ 3D CAD models, rather than being produced within the model. If there are variations on site for any reason, the model offers no output to detect them and compare them with what was planned initially.

2.2.4. ATLAS

ATLAS is a European Union funded project, focused on the development, implementation, demonstration and dissemination of semantical project information models, taking the IRMA (an e-mail conference organised by Thomas Froese in 1993) results as its starting point (Tolman 1999).

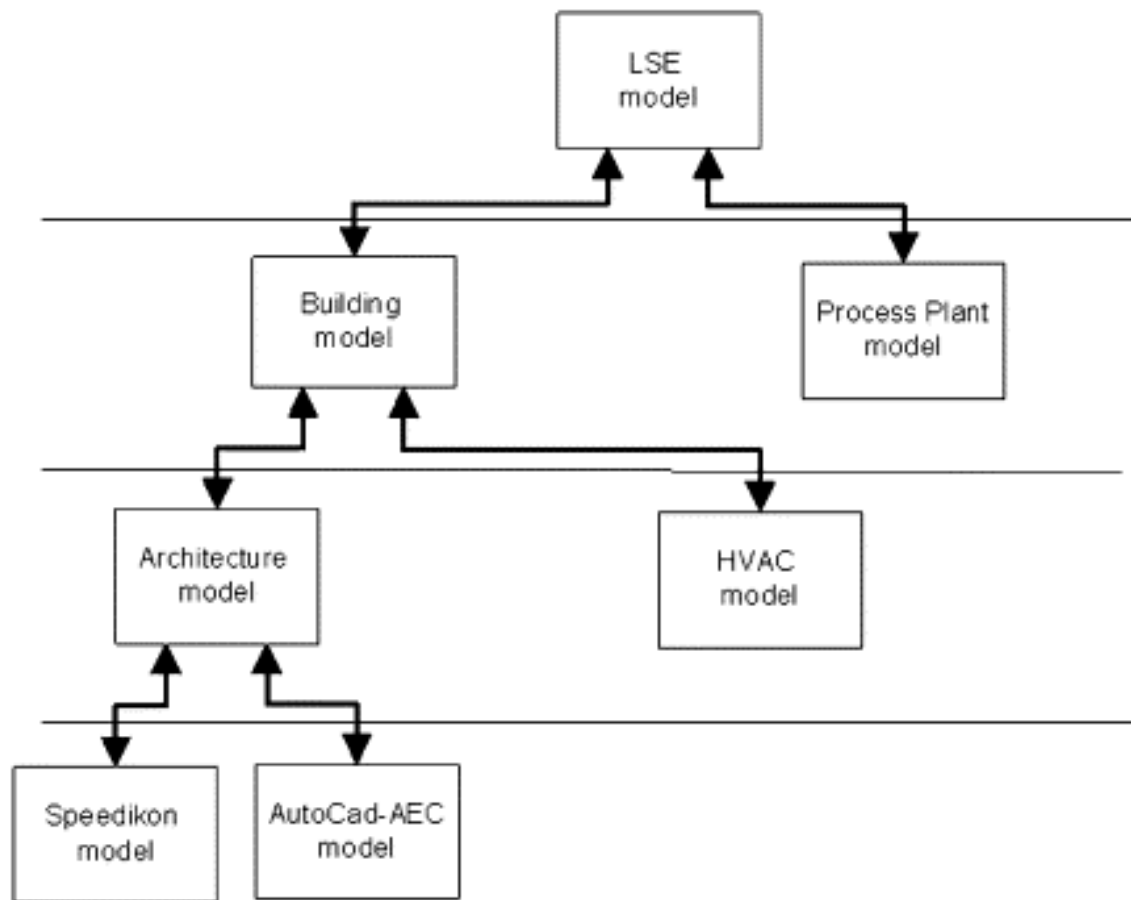


Figure 2.3: The ATLAS model hierarchy.(Tolman 1999)

In figure 2.3, boxes denote a model, or schema. Arrows denote mappings, or translators. Higher in the hierarchy entities are more abstract (SeparationObject, instead of OuterWall). In the top layer the large-scale engineering (LSE) model provides an integration mechanism between different sectors of the LSE industry. One layer below, the building model and process plant model provide an integration mechanism between disciplines of their own sectors. Again one layer lower a number of discipline models (Architecture, structural engineering, HVAC engineering in the building case) provide an integration mechanism between different applications of the discipline (Tolman 1999).

In the ATLAS project, the research team mainly investigated the integration, data exchange and communication strategies using STEP data model. Furthermore, there was an attempt to employ knowledge-based and case based systems to support specific

business functions, to play a major role with respect to the development of versatile, easy to use - easy to modify – rule based converters and mapping semantical models by reasoning (Poyet 1994).

Although the ATLAS project helped prove that further computer integration is likely and necessary for the construction industry, this project also failed to cover the accurate construction progress monitoring aspect by relaying solely on inputting planning stage data.

2.2.5. VIRCON

The Virtual Construction site (VIRCON) project brings together academic and industrial collaborators in an attempt to push forward the state of the art in construction project planning. The project was funded by the UK government, with the prime objective to develop a strategic decision support system for construction project and space planning within a desktop environment (Dawood, Scott et al. 2002).

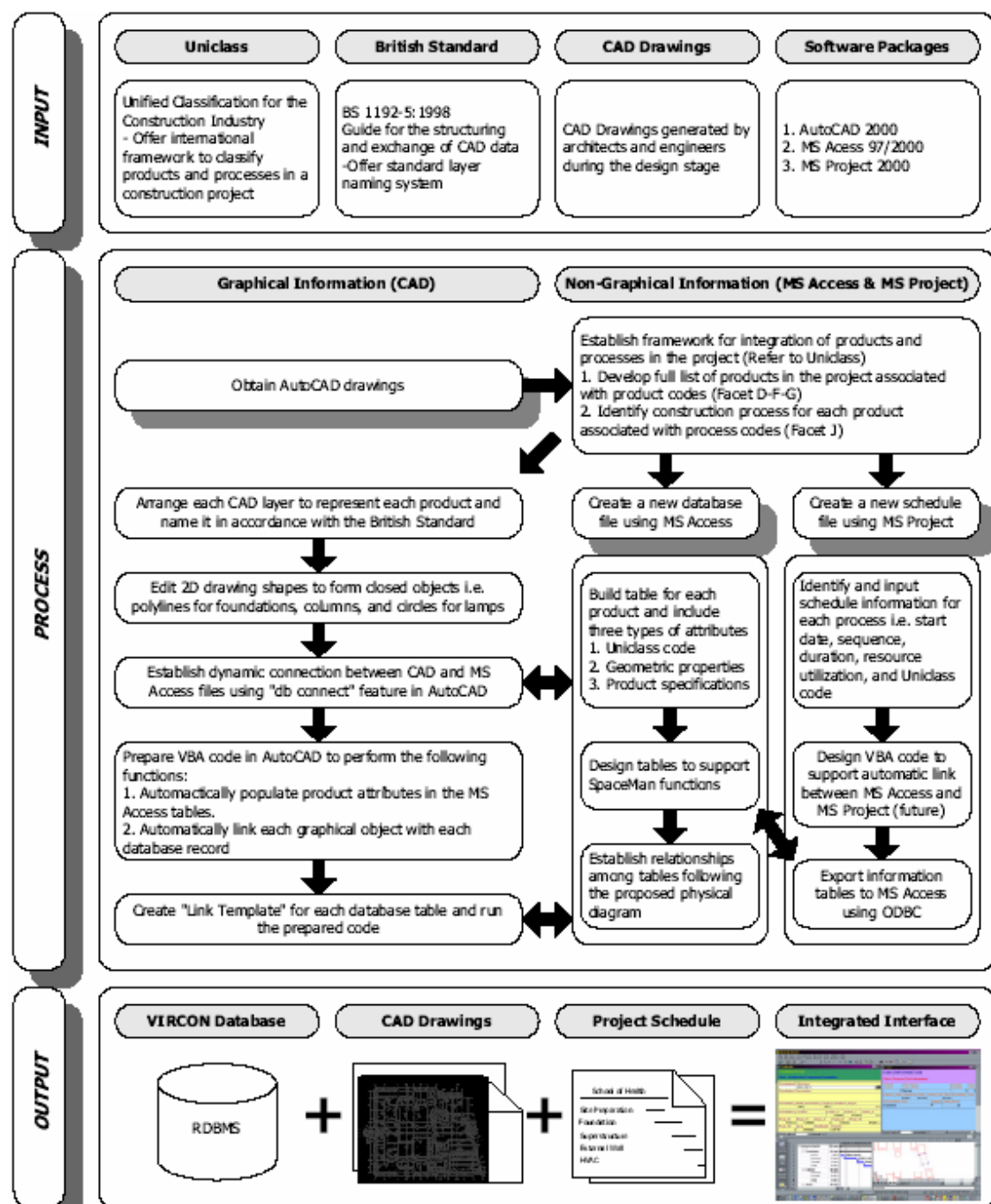


Figure 2.4: Overall process of VIRCON database (Dawood, Sriprasert et al. 2001).

In VIRCON projects 3D CAD models are created within AutoCAD. These models are then allocated to standard layers, e.g. foundation objects to foundation layers, column objects to column layers, etc. In layer allocation, BS1192-5 1998 is used as layer standards.

While 3D models are created in AutoCAD, schedule and resource allocation tasks are done in MS Project software. With respect to schedules and resource allocations, the process comprises of five steps (Dawood, Scott et al. 2002) which are: (1) developing a product-based work breakdown structure; (2) grouping CAD products; (3) linking product groups with activities; and (4) population of the VIRCON database. Product-based work breakdown structure is a medium that allows systematic and consistent integration of product and process data. The structure was broken into four levels of activities. Then these activities are linked to the 3D models using VBA. After all product groups are generated, the fifth step is to link these CAD groups with activities in MS Project

In the VIRCON database, project data comes from AutoCAD, process data comes from MS Project. Auto CAD data can be either 3D or 2D. All product data is populated to the database using a VB routine which has been dubbed DataExtractMan. DataExtractMan is an AutoCAD macro that automatically interprets CAD layers and extracts 3D-2D information into the VIRCON database (Dawood, Scott et al. 2002). Creators of the model say that, this is a fully automated routine and saves a huge amount of time and effort for the project manager, providing that product information has been properly layered in CAD using BS1192-5.

Once the project data has been set up, it can be read for the purposes of assigning plant and temporary works to weekly 2D plan. This is done by using prototype software called 'PlantMan'. PlantMan incorporates the 'ClashMan' tool which checks clashes between assigned plant and temporary installations. This is then stored as a DXF file to be accessed by another tool for marking-up space availability dubbed 'AreaMan'. For the space and time optimisation there is another tool called 'SpaceMan'.

There are two visualization tools within the VIRCON project:

1. ProVis- a 4D tool developed as a plug-in to AutoCAD 2000 and AutoDesk Architectural Desktop (ADT 3.3) for visualising traditional CAD or IFC 1.5.1

products. The tool also highlights locations of spatial overload as identified by SpaceMan.

2. SpaceVis- a 4D tool for visualising construction products and movement of plants/temporary objects in VRML, a VR web-enabled format (Dawood, Scott et al. 2002).

After an experiment, a group of evaluators commented that the VIRCON tools are easy to use, useful for strategic decision making, and they found the visualisation helpful and informative (Dawood, Scott et al. 2002).

Users of the system also stated that it may be unrealistic to be able to obtain the necessary information needed by VIRCON early enough from contractors and project team members due to the fact that contractors tend to be secretive about the plant and material sources they have, in case this information can be used against them later on.

The VIRCON creators suffered the common problems related to integrating different third party software products with each others. These third party package programs were already in existence and the new development had to fit in around them. This required a reactive approach, where much of the research team's focus had to be on component interoperability (North, Winch et al. 2003).

Like other nD prototypes, VIRCON also relies on planning data available at the end of the design stage and needs to be fed by updates according to the changes happening on the construction site. Its reliability depends on whether or not the 3D project design remains unchanged. It can be argued that allocating CAD objects to standard layers and then exporting the layer properties to Access tables requires additional labour effort of operators. It is also that in architecture practices in the UK, following British Standards in layer configuration is not an established norm yet.

Another problem is that the Architectural projects are not being drafted with closed poly-lines in AutoCAD, so the creation of “closed areas” to create measurable zones also requires enormous manual input even before the input stage can progress.

It can be argued for all of the nD applications that, they do not produce any new data, instead they mix and match the data available before the construction even starts, hence they all have some validity problem hidden behind.

2.3. Automated Data Capture from Construction Sites via Barcode System

Barcodes are very useful in management of stock within the construction site and the supply chain. A new branch of automation in construction management emerged with the introduction of barcode technology. An example to the implementation of such a technique to the prefabricated construction design and manufacturing is outlined as follows.

Bar code applications are implemented in three phases: (1) design, (2) manufacturing, and (3) construction erection. Through the application of the bar code system, the data integrity and consistency between different phases is ensured (Cheng and Chen 2001).

(1) Design phase: During the design phase, the structural components for prefabrication are analyzed and divided after detailed design layout and structural analysis are completed. According to the principles of the prefabricated element coding system, each prefabricated unit is assigned with a unique code. This code is the identification of the element, which will be used for manufacturing, transport, storage, and construction installation.

(2) Manufacturing phase: The structural components are produced in the plant based on the schedule of production. The bar code assigned for each element in the design phase is used for the creation of shop drawings, production schedule, and inventory control of the finished products in the storage yard.

(3) Construction erection phase: Before the construction commences, managers have to prepare the installation schedule according to the construction plan and develop a lifting schedule database. The manufacturing and transport schedules are reconfirmed based on the installation schedule and fed back to the manufacturer as a reference for planning and revising the production plan. The consistency of information between the manufacturing and construction phases can be assured. Through the identification of the bar code, managers can record the prefabricated elements transported to the site, identify the storage area, and enquire into the erection sequence and schedule by using ArcSched installed in the main computer of the control center.

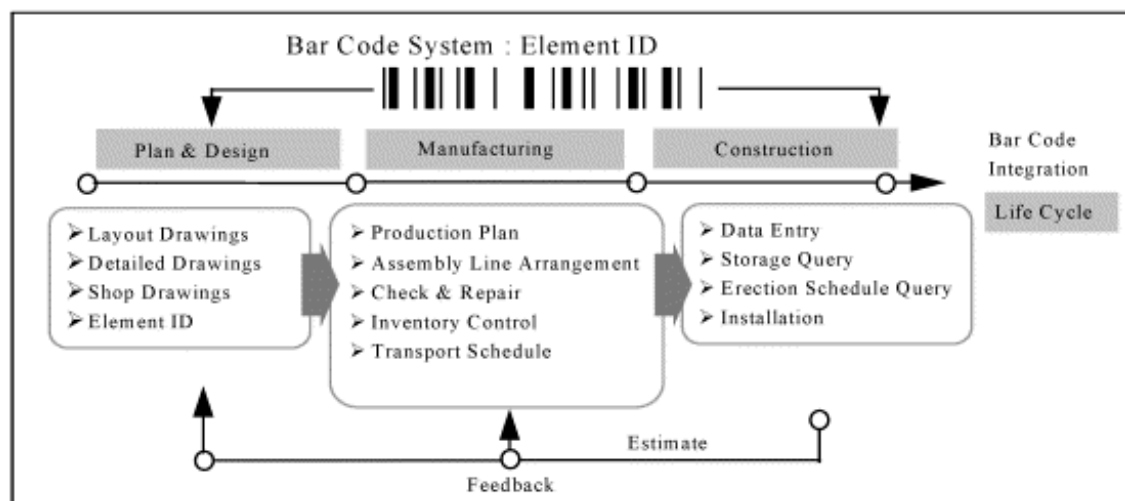


Figure 2.5: Construction integration using bar code(Cheng and Chen 2001)

Data collection efficiency is improved by using the automated bar code collector to gather and enter the job site data (Cheng and Chen 2001). There are two stages for using the wireless bar code transmitting system to collect the bar code of the prefabricated unit: (a) job site entrance and (b) storage yard. When the prefabricated units are transported to the job site, the bar codes of the prefabricated units are read by the bar code collector at the site entrance. Through wireless transmission, the data is transmitted to the control centre and saved in the associated database. To lift the units from the storage yard for installation, the bar codes of the units are also read and transmitted to the control centre to check the related erection information such as position, sequence, and date.

Limitations associated with barcode technology can be identified as follows (Dean 2007);

- They have a very low storage capacity,
- They lack durability (mostly paper based),
- They have a relatively low read range,
- They can only be read when a line of sight is established,
- Barcodes can only be read one at a time,
- They can not be written to or programmed.

Another limitation of barcode based automated data capture is the obvious difficulty of attaching barcodes on products without any prefabrication background. Construction components can be barcode attached relatively easily when they are being manufactured within a factory. However, in-situ construction operations are less suitable for such applications. The main strengths of barcode based methods lies with manufacturing processes, storage management, supply chain management and financial control, rather than basic construction operations themselves (e.g. brick laying, in-situ concrete casting).

2.4. GPS and GIS Integrated Construction Management

Global Positioning System (GPS) and Geographic Information System (GIS) can offer capacity in progress measurement. For example the construction vehicles can be tracked. The purpose is to transfer real-time location information of construction material and equipment being carried to a construction site. Integrated GPS and GIS technology helps to improve efficiency and to increase profits by providing real-time

vehicles locations and status reports, navigation assistance, drive speed and heading information, and route history collection (Li, Chen et al. 2004).

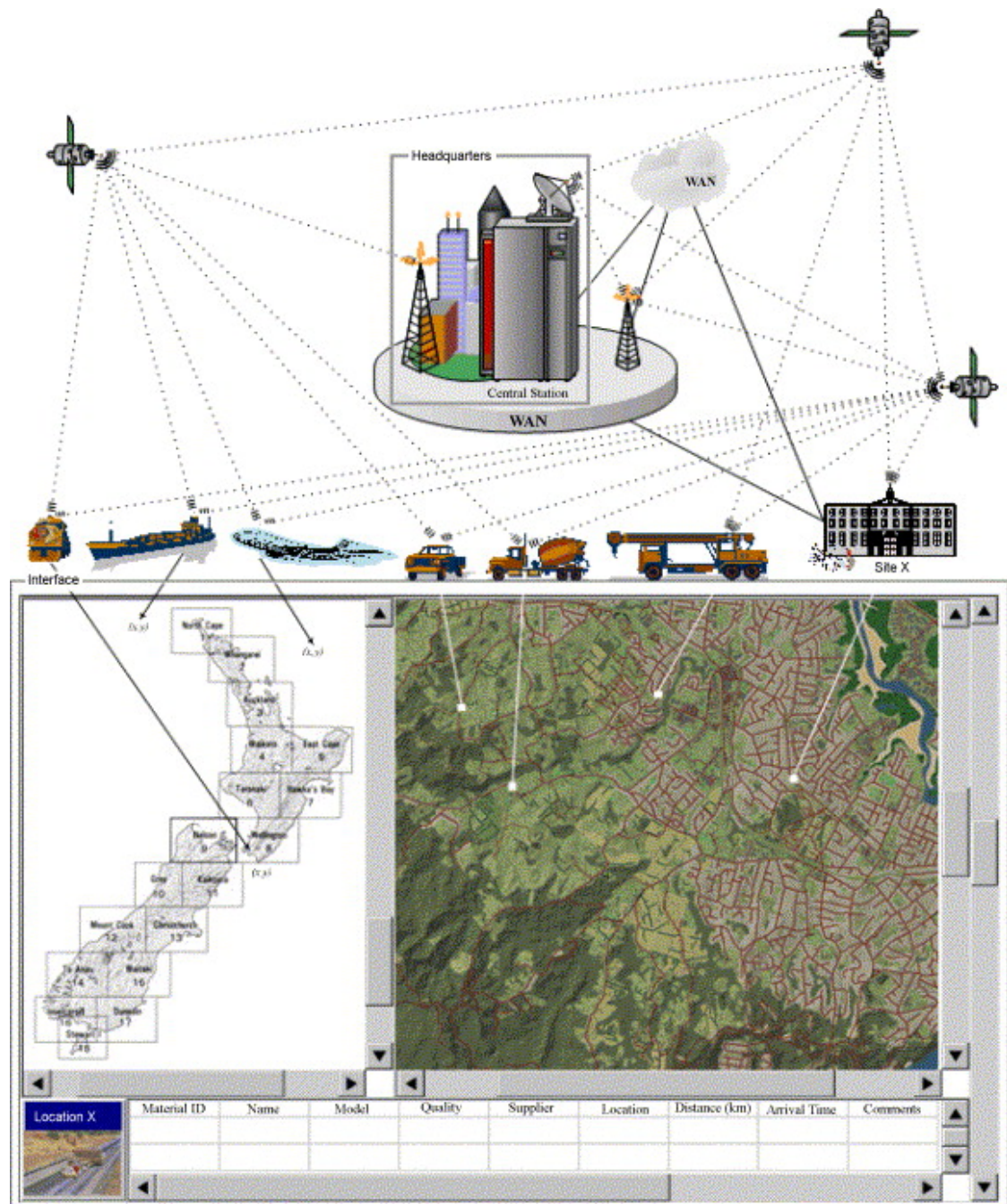


Figure 2.6: Framework of the GPS and GIS Integration (Li, Chen et al. 2004)

2.5. Photogrammetry Applications

Obtaining numeric information from photos is the subject of photogrammetry. Using the basic rules of optics, geometrics and maths, it is possible to obtain accurate measurements from photos (Wolf 1983).

A few decades after the invention of photography, Albert Meydenbauer, in 1858 was one of the first to use measurements in photographs for the purpose of 3D reconstruction. Since then many developments took place in the area of photogrammetry, one of them being the transition from photographs on film to digital images. One aspect, however, did not change: object reconstruction by photogrammetry is still based on the reconstruction of 3D points (Vosselman 2001).

Photogrammetry traditionally has dealt with topographic data. Today, often in connection with Remote Sensing (RS) and GIS, it continues to do so. In addition to its traditional involvement in terrain modelling, close-range applications of photogrammetry such as architectural, terrestrial, medical, microscopic, x-ray and moiré have always been active and in demand (Coltekin 2006). Some of the photogrammetry applications and their suitability for the building industry and construction progress measurement areas are reviewed below.

2.5.1. Semi-automatic CAD based reconstruction of industrial installations

This research (Vosselman 2001) aims at reverse engineering of industrial installations using photogrammetry knowledge and digital images.

A library of components is proposed containing common fittings elements used in industrial installations. These generic objects are made of unions of simple 3D solid CAD objects called “Constructive Solid Geometry” (CSG) (Mortenson 1997). The model of the industrial installation is reconstructed by repeating the following steps for each simple model in the scene (Lang and Forstner 1996).

- First, the image analyst interprets the images and selects an appropriate model from the library. This model, with some default shape, is placed somewhere in the 3D object space. When the orientation of an image is known, the object model can be projected into this image. In the image the visible object edges are displayed as a wire frame model (figure 2.7a).
- Next, the image analyst roughly aligns the object model to the image of the object by dragging the nodes and edges of the wire frame to the correct positions. By doing so, the image analyst implicitly modifies the position, rotation and shape of the object model (figure 2.7b).
- Although the image analyst could precisely align the object model, both the accuracy and the speed of the reconstruction improve if the previous step is followed by an automatic fitting of the wire frame to the object's edges in the images (figure 2.7c) (Vosselman 2001).

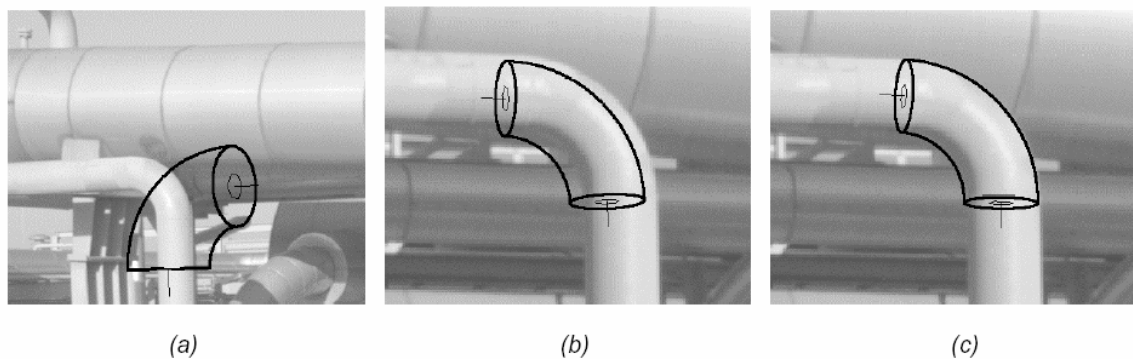


Figure 2.7: Interactive alignment of a CAD model to an image. (a) Wire frame of an elbow model projected into an image with arbitrary orientation. (b) Model after approximate alignment by the image analyst. (c) Model after fitting to image gradients in multiple images (Vosselman 2001).

The model relies on establishing a reference between the coordinate systems of the image and the scene. The first object fitted to the CAD space establishes the orientation. When the reference system is established, new objects can be incrementally fitted to the drawing space to create the whole 3D model of the installation subject to the survey.

The proposed method has proven useful when an as-built situation has to be created because the plant design maps are no longer available or up to date (Tangelder, Ermes et al. 2003).

The draw-backs of the proposed method are its reliance on the operators' manual interpretations and associated difficulties in having to capture images of everything that needs to be modelled. As it is, Vosselman's method is an innovative surveying tool. However, considering that the currently available alternatives are limited to traditional surveying techniques, (involving actual measurements of everything on site), the proposed model still promises lots of potential.

2.5.2. PhotoModeler

PhotoModeler is a close range photogrammetry software application. It has functionality ranging from accident reconstruction, archaeology and anthropology, architecture and preservation, film, video and animation, forensics and plant & mechanical engineering.

PhotoModeler software is widely used as a measurement and modelling tool in architectural, preservation, conservation and cultural resource management applications (EOS 2007).

Here is a list of areas PhotoModeler can be used for;

- Documenting and measuring older buildings and structures for conservation and preservation,
- Generating 3D models for visualization and view studies,
- Generating elevation drawings of your existing structures,

- Generating rectified photographs of facades from single and multiple photo projects,
- Producing photo-textured 3D models for realistic walk-bys,
- Surveying existing structures and objects.

PhotoModeler is a popular example of how photogrammetry can help the building industry in its measurement and surveying needs, however it comes with its own limitations. The product relies heavily on user input. It takes a very long time to produce very simple 3D models. In two research projects done with PhotoModeler, it was found to be too impractical to be used for day to day measurement activities (Hadwan, Kaka et al. 2000), (Knight and Kaka 1998). 3D models created by this program are made of surfaces, not solid objects; therefore, these models can not easily be used for volumetric calculations compared to the ordinary CAD models. No construction knowledge has been used in the creation of the software, therefore; it doesn't offer any automation that makes it easy to use in the building industry.

2.5.3. Desktop Digital Photogrammetry System (DDPS)

This is a desktop software photogrammetry solution that enables users to quickly and efficiently capture accurate 3D vector data and orthophotos from digital photography (3Dmapper 2003).

The DDPS also has application in Close Range Photogrammetry, enabling users to use photos to obtain accurate field measurements to create as-built 3D computer models. In addition, the DDPS can provide the industrial plant geo-coding for use with Asset Management Systems, to facilitate planned maintenance of plant, equipment and buildings. Some of the application areas of the package can be listed as follows;

- Mining and Mineral Exploration

- Oil and Gas Exploration
- City/Town Planning Studies
- Agricultural Planning
- Farm Planning
- Forestry Planning
- Land Use Management

All the functions are executed by four programs offered under DDPS. Although these programs can be used without previous photogrammetry experience, they are very time-consuming when used for construction progress measurement purposes, as the product of one program is being used as an input for the other, and these processes also require huge amounts of user input. No construction knowledge has been used in creation of the software, therefore; it doesn't offer any automation that makes it easy to use in the building industry.

2.5.4. REALVIZ

RealViz ImageModeler, is a software application developed for creating 3D models from photos (RealViz 2008). The application is a very similar product to PhotoModeler. It has a very similar interface, and does very similar tasks.

It also has similar practicality issues. Produced 3D models are made of surfaces, not solid objects; therefore these models are not easily used for volumetric calculations. No construction knowledge has been used in creation of the software, therefore; it doesn't offer any automation that makes it easy to use in the building industry.

2.6. Terrestrial Laser Scanning Applications

Terrestrial laser scanning is described as the use of a ground based device that uses a laser to measure the 3D coordinates of a given region of objects surface automatically, in a systematic order at a high rate in (near) real time (Bryan 2003).

This technology is available to create point cloud 3D models of objects. These point clouds can be later processed again to be converted to 3D CAD models of the surfaces. Point clouds refer to a collection of XYZ coordinates in a common coordinate system that portrays to the viewer an understanding of the spatial distribution of an object.

Within the built environment, use of a 3D laser scanner enables digital documentation of buildings, sites and physical objects for reconstruction and restoration including cultural heritage. It also enables the creation of educational resources within the built environment, as well as the reconstruction of the built environment. Besides, it has also potential to accurately record inaccessible and potentially hazardous areas (Arayici 2007).

The system is applicable to all 2D and 3D surfaces, and rapid 3D data collection is possible. The technology is ideal for 3D modelling and visualisation purposes but there are some limitations. It does not always work properly in a rainy or sunny environment. 3D data sets (point clouds) need post processing in order to gain usable output. It is also found to be difficult extracting the edges from indistinct data clouds (Arayici and Hamilton 2005). Obstructions (temporary or permanent) found between the scanner device and the target area also seem to create significant void regions on the created point clouds.

Although the technology of terrestrial laser scanning is rapidly developing, due to the named drawbacks of the system, it is found to be unsuitable for the purpose of construction progress measurement. The device which is used for measurement purposes is very fragile and is vulnerable to the usual hostilities of a construction site.

2.7. Full Automation and Computer Vision

All of the construction management tools reviewed in this chapter require partial or full intervention by an operator. They need data either obtained by classical surveying methods, by photogrammetric measurements or digitally captured scanning results still requiring significant effort during post processing etc. Achieving full automation in obtaining and processing data from construction sites is still a challenge yet to be fulfilled.

Computer vision (Trucco and Verri 1998) is a vast field of research with great potential for the construction industry (Trucco and Kaka 2004). Below is a review of the named research in the area.

2.7.1. Automatic Progress Assessment on Construction Sites Using Computer Vision

This research is concerned with 3D object recognition. 3D object recognition is defined as the problem of detecting and possibly locating a 3D given object, or model, in a video or set of images.

The proposed model involves two different algorithms: “algorithms using CAD-like models” and “algorithms using iconic models”.

Only a subset of objects can be modelled by manageable 3D CAD like models for recognition purposes (Trucco and Kaka 2004). Objects changing in time, like a progressing construction site would result in CAD models that are too complex to be manageable or they would need constant updating. For this problem the “iconic models” alternative is proposed. In this model, 3D objects are represented by a set of significant views. The proposed algorithm (using Housdorff Distance (Huttenlocher, Klanderman et al. 1993)) compares these representative views of building elements with the images taken from the construction site. If those iconic views detected on the digital images taken on construction site, model assumes, progress regarding to this building element

is achieved. The model can also automatically count how many times a building element is detected on the images.

Using the Housdorff Distance method the model compares iconic views with construction photo and detects the similarities with a similarity score. While these similarity scores can perform as a guide about how close the matching between the images were, they also indicate a potential weakness of the model.

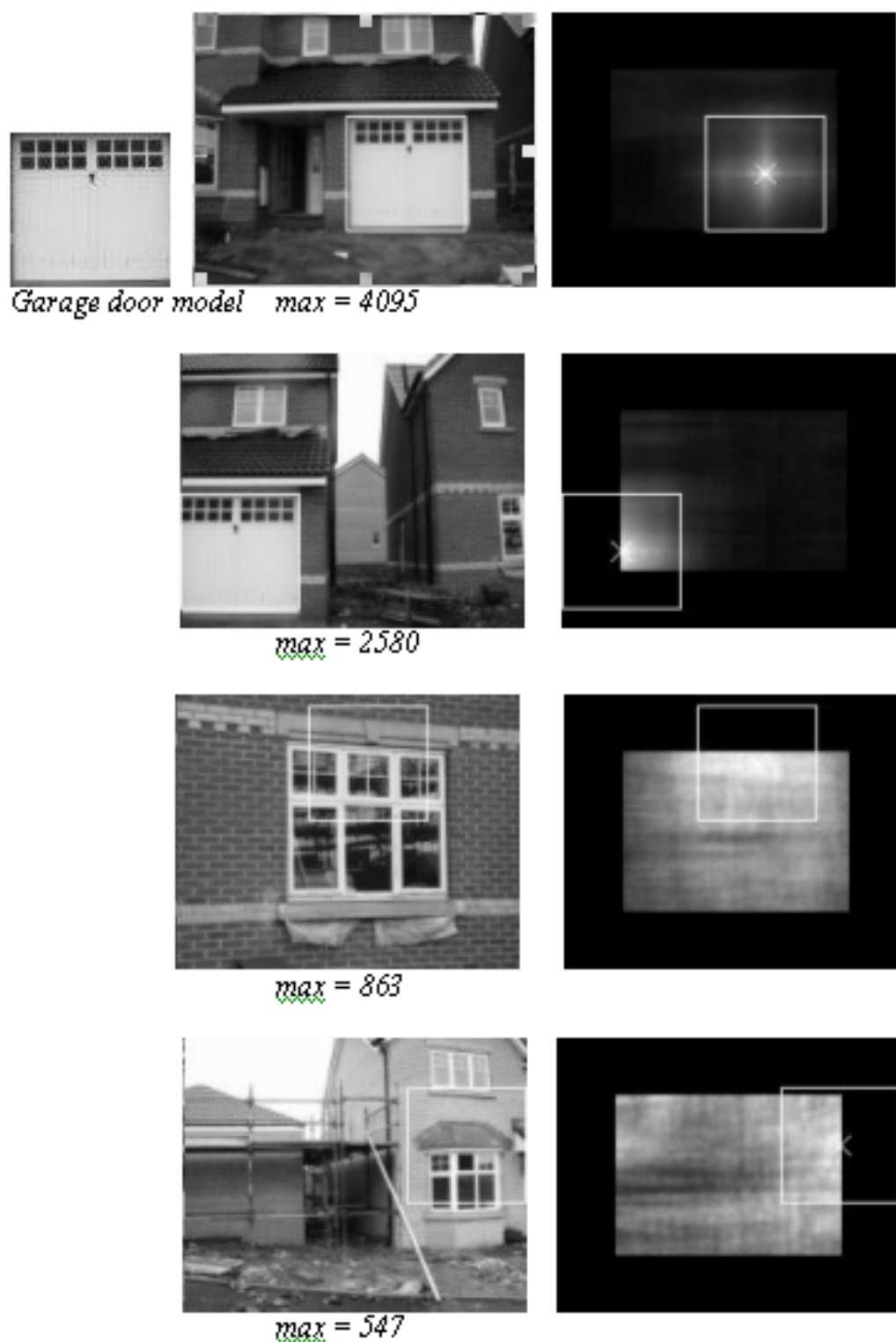


Figure 2.8: Garage door model (top left) and its computed location in a selection of input images (left column) with associated similarity surface (right column, the brighter the higher the surface value), generated by the algorithm. The cross shows the position of the maximum (Trucco and Kaka 2004).

The model aims to find a group of pixels that proportionally match with the iconic models as close as possible. Since the construction site pictures are often highly occluded or dark, the algorithm sometimes detects temporary structures like scaffolds or random windows instead of a garage door. While rapid development in this area and the huge potential that full automation can offer is appreciated, the proposed model is far from being a working prototype.

This model is different from the previous examples. It aims to eliminate human intervention from the data connection so that a higher level of automation in progress measurement can be achieved. It is focussed directly at the physical construction activities and doesn't rely on planning and design stage information. Therefore, it provides a form of as built information rather than making projections about the future.

2.8. Conclusions

A literature review in the computer integrated construction area revealed that the studies in this area are grouped around a few popular research approaches.

A large proportion of the research is focusing around the subjects of nD modelling, integration of different data formats, web enabled construction management and integrating different package software with each others. The most recent research is aimed at achieving all of the named aspects of the computer integration problem, under the same solution package.

However, this family of research has the common problem of being constrained to using project data available during the planning stage. Planning data (in the form of network diagrams) and drawing data (in the form of 3D CAD models) are all available as a result of the design and planning stage. These outputs are taken and integrated to form 4D or nD models so that projections about the future of the project can be predicted or visualised. These 4D models do not provide additional information about the project, but do provide valuable visualisation.

These models also require constant manual updating of planning stage data against as-built data in order to remain accurate. They offer no automation to the collection of data to make these updates regarding the changes that occur during the construction phase. Any unplanned alterations of the design information have the potential of rendering these tools useless.

Since variations in schedule and budget are common in the construction industry, these changes must be monitored, measured, and managed. These common changes and the need for creating accurate as-built data of various installations, create a new direction in computer integration in construction. This group of researchers are focused on obtaining data from construction sites in order to monitor changes by means of computer integration.

There are various ways of automatic 3D data capture from construction sites in order to monitor or document the current state of the construction. In this chapter, three main approaches of 3D data capturing methods were reviewed. These are the photogrammetry based approach, laser scanning based approach, and the full automation via computer vision. In addition to that, barcode technology applications and their potential for automated data capture was reviewed.

Adaptation of barcode or GIS/GPS technologies gives impressive results for stock control and supply chain management. It offers automatic data capture potential for the assembly of prefabricated building components as well. However, the application is found to be unsuitable outside the manufacturing industry and logistics operations. Custom made products like masonry walls or in-situ columns are not suitable objects to be attached with barcodes.

Laser scanning methods have been found to be unreliable, due to the fact that occluded images create huge gaps of information and the technology used in scanning is often not suitable to work in the rain or under intensive sunlight. Data obtained by laser scanners is not ready to be used before post-processing either. This method was not found to be

suitable for the purpose of obtaining 3D as built data due to the drawbacks reviewed in this chapter.

Full automation seems to be the main challenge to achieve in this area, but the technology of computer vision is not reliable at the current state of the knowledge for the purpose of this research. Technology offered by computer vision is able to distinguish a garage door from a window, but unable to distinguish two similar types of wall from each other if the size proportions of the walls are the same. Accuracy of the iconic recognition needs improvements perhaps via further artificial intelligence. This approach was also found to be unsuitable for the purpose of this research.

Photogrammetric measurements offer reliable results at the cost of more human intervention. This approach offers the possibility of using a hand held camera as a measurement tool. Inaccessible parts of the construction can be measured via digital images. This method offers complete independence from reliance on the planning and design stage information. Hence, it can be used to re-evaluate, or monitor the changes during the project life-cycle. The problem with this method is excessive human intervention. By means of automation and integration of construction knowledge, the photogrammetry based measurement approach can be improved.

The research subject of this thesis is to improve automation in the photogrammetric approach in order to measure progress, and reduce the human intervention in measurement activities while maintaining the accuracy and convenience of photogrammetry.

Chapter 3: Current Progress Measurement and Planning Methods	46
3.1. <i>Introduction</i>	46
3.2. <i>Gantt Charts, Network diagrams and Critical Path Analysis</i>	47
3.2.1. <i>Gantt Charts</i>	47
3.2.2. <i>Network Diagrams</i>	49
3.3. <i>Earned Value Analysis (EVA)</i>	52
3.4. <i>S Curves</i>	57
3.5. <i>Line of Balance Technique</i>	61
3.6. <i>Cash Flow Calculations</i>	62
3.7. <i>Conclusions</i>	63

Chapter 3: Current Progress Measurement and Planning Methods

3.1. Introduction

Time, cost and quality are probably the most well known project success criteria. Delivering a project within budget, on time and up to a quality can only be possible with good planning.

Delays in construction can cause a number of problems in a project such as late completion, lost productivity, acceleration, increased costs, and contract termination. The party experiencing damages from delay needs to be able to recognise the delays and the parties responsible for them in order to recover time and cost (Arditi and Pattanakitchamroon 2005).

Project failure is defined “when the final results are not what were expected, even though the original expectations may or may not have been reasonable (Kerzner 2003)”. Exceeding the initial budget of the project, failing to deliver the project on time or delivering a low quality product are the kind of results that make a project a failure. Planning is a way of avoiding such unpleasant results.

Project Management discipline has long been using various tools to keep variations in time, cost and quality targets under control. A wide variety of software packages are now available to project managers to partially automate these tools.

This chapter reviews these traditional methods of construction management. The aim of the chapter is to introduce the current status of construction management tools and explain how they can benefit from the proposed model in this thesis.

3.2. Gantt Charts, Network diagrams and Critical Path Analysis

Project managers need to find better techniques to cope with complexity issues due to the massive amount of data involved in project planning. Gantt charts and project network diagrams are graphical representations of project schedules. As they are developed, managers can improve the quality of technical and cost data presentation to the customers. The most common graphical techniques and their applications are outlined here.

3.2.1. Gantt Charts

In a Gantt chart, an activity is represented by a horizontal line. Length of the line represents the duration of the activity. Various activities of a project are listed in the same column. Concurrent activities in a project partially or completely overlap in a vertical line.

Ongoing activities are presented as secondary lines within the bars on the chart. This gives a simple but striking representation of ongoing activities and if the data on the chart is correct, any activities that are behind or beyond the schedule can be seen at any time of project duration (Lockyer and Gordon 1991). Figure 3.1 is an example Gantt chart created with MS Project.

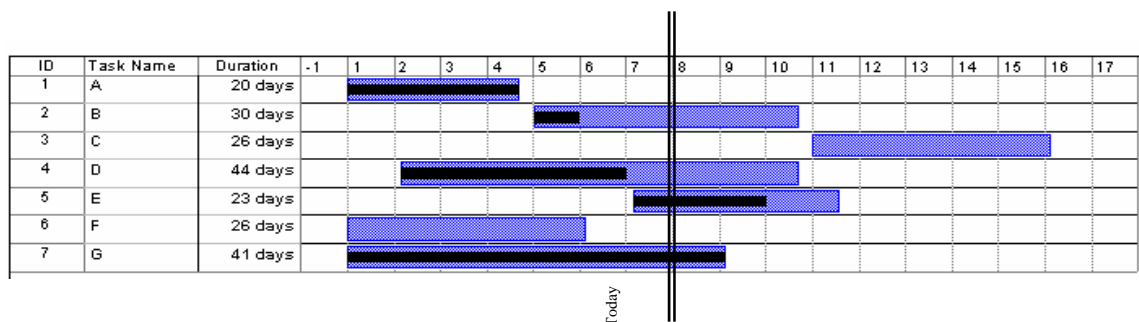


Figure 3.1: Gantt (bar) chart representation of a project.

If the chart in figure 3.1 is correctly filled in, the following information is readily available:

Activity A should be completed and, in fact it is.

Activity B should be 50% complete, but it, is only 17% finished.

Activity C should not be started and, in fact, is not started.

Activity D should be 62% complete and, in fact, is only 55% finished.

Activity E should be 17% complete and, in fact, is 60% finished.

Activity F should be complete and, in fact, is not started.

Activity G should be 87% complete and, in fact, is complete (Lockyer and Gordon 1991).

Bar charts provide only a vague description of how the entire program or project reacts as a system, and have three major limitations (Kerzner 2003). First, bar charts do not show the interdependencies of the activities; therefore they do not represent a “network” of activities. This relationship between activities is crucial for controlling program costs. Without this relationship, bar charts have little predictive value. Whether or not an activity can start earlier than the scheduled time can not be deduced from a bar chart. Bar charts can not reflect the true project status because elements behind schedule do not mean that the program or project is behind schedule. The third limitation is that the bar chart does not show the uncertainty involved in performing the activity and, therefore, does not readily admit itself to sensitivity analysis. For instance, what is the shortest time that an activity might take? What is the longest time? What is the average or expected time to activity completion (Kerzner 2003)?

Regardless of named constraints, computer package software producers supply reasonably sophisticated products to integrate the convenience of bar charts to construction project management applications. The most common and commercially successful ones include Ms Project, Primavera Project Planner, Superproject Plus, Harvard Total Project Manager (HTMP), PROMIS, and TimeLine (Dennis 2003). In such software packages activities are represented as moveable bar objects. As the bar chart is developed, network relations charts of the project are also generated in the background.

3.2.2. Network Diagrams

The network diagram is more effective than the bar chart as it shows the logical sequences between activities (Arditi and Pattanakitchamroon 2005). In larger projects where Gantt charts are inapplicable, network diagrams come in handy. Common network diagrams are;

- Program Evaluation and Revive Technique (PERT),
- Arrow Diagram Method (AMD or sometimes called Critical Path Method (CPM))
- Precedence Diagram Method (PDM),
- Graphical Evaluation and Review Technique (GERT) (Kerzner 2003)

Critical Path Method (CPM) schedules add another dimension to schedule analysis as they provide schedule analysts with a critical path, float consumption, and the opportunity of utilising what-if methodology (Arditi and Pattanakitchamroon 2005).

Network diagrams involve precedence relations of activities with each others. Likely starting and ending times of each activity and expected durations are located within the

boxes that make the network diagram. Once the diagram that represents the main structure of a project is satisfactorily generated a calculation can be carried out to estimate total likely project duration. In many cases the discovered duration of the project might not be acceptable. In such a case, activities dictating this duration (critical path) are examined to discover whether or not the project duration can be shortened. By increasing the resources given to the activities on the critical path, a total reduction from the project duration can be achieved. Increasing the resources generally means a greater financial commitment. More often a trade-off analysis may have to be considered between a greater cost and longer project duration alternatives.

There is always a ceiling for the level of resource allocation for individual activities. This means that when this ceiling is approached, resource increase will not be possible and hence, project duration would not be shortened. For example, an increase in the number of bricklayers in a construction can increase the speed and reduce the duration of bricklaying activity at a greater cost, but there is always an upper limit at which level no more bricklayers can possibly work concurrently, due to the space or efficiency constraints. In such a situation the only alternative may be increasing the total project duration.

Chapter 3

Current Progress Measurement and Planning Methods

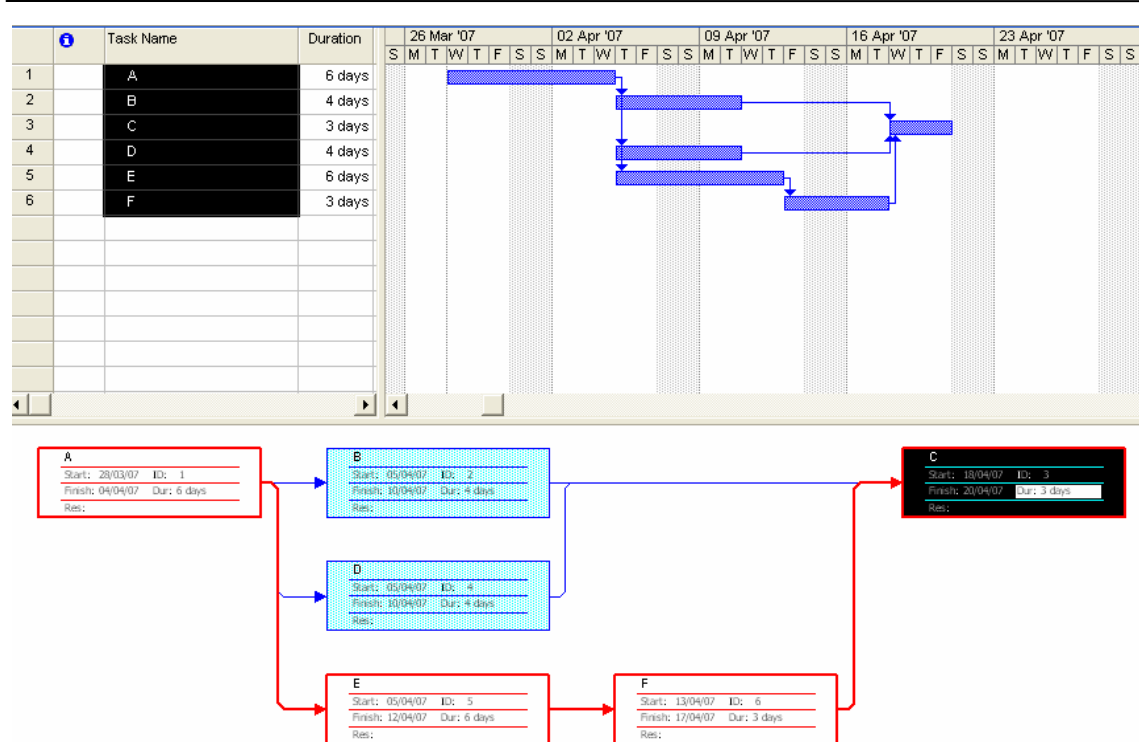


Figure 3.2: Network diagram with critical path, and bar chart representation of a project.

The project representation on figure 3.2 shows the relation between a bar chart and a network version of the same project. In this example the activities A, E, F, and C are called critical activities. Duration of these activities determine the total project duration. Project decision makers can reduce the total duration of the project by playing on these activities but when another set of activities become critical or when these activities can not possibly be finished in any shorter durations the minimum time limit at which the project can be finished is now reached.

Network diagrams can also be used for estimating project durations via more statistical methods. If the decision maker is statistically sophisticated, he can examine the standard deviations and the probability of accomplishment data (Kerzner 2003). Suggested formula is as follows;

$$t_e = (a + 4m + b) / 6 \quad (\text{Equation 3.1}),$$

where t_e = expected time, a = most optimistic time, b = most pessimistic time, and m = most likely time.

Some of the main problem areas with network diagrams must also be mentioned. According to Kerzner there are, in such systems, planners and doers. In most organisations PERT planning is performed by the program office and functional management. Yet once the network is constructed, the planners and managers become observers and rely on the doers to accomplish the job within time and cost limitations.

Another problem is that, unless the project is repetitive, there is usually little historical information on which to base the cost estimates of most optimistic, most pessimistic, and most likely times. This information can often end up being estimated unreliably.

Network diagrams are based on the assumption that all activities start as soon as possible. This assumes that qualified personnel and equipment are available. Regardless of the quality of the plan, there are almost always differences in performance times from what would normally be acceptable.

Some of the common package software being used in construction industries that produce network diagrams can be named; Super Project +, Harward Total Project Manager (HTMP), Microsoft Project, PROMIS, and QWIKNET (Dennis 2003).

3.3. Earned Value Analysis (EVA)

Network diagrams and bar charts are useful tools for controlling the time aspect of the project while they have limited use for cost planning and control purposes. For this reason Earned Value Analysis (EVA) is a common tool used.

“If you can’t measure it, you can’t manage it”. Whether one trusts the validity of this common phrase most of the time or all of the time, measuring the true progress of a project presents a formidable task. Given a baseline plan, projects typically report a

measure of the completed work and compare it to that scheduled. Similarly, most projects can and do measure the current cost and compare it to the planned spending (Cioffi 2005).

Anytime a construction cost engineer takes the time to verify the physical work actually accomplished against the payment invoices being requested, prior to paying the supplier, the cost engineer is utilising a simple form of earned value (Fleming and Koppelman 2000). It is an analysis to find out true performance of the project. The APM, PMI, ISO 10006 and BS6079 require the use of earned value analysis for project cost data collection and reporting.

Earned Value Management (EVM) is a methodology used to measure and communicate the real physical progress of a project and to integrate the three critical elements of project management (scope, time and cost management). It takes into account the work complete, the time taken and the costs incurred to complete the project and it helps to evaluate and control project risk by measuring project progress in monetary terms (Vandevoorde and Vanhoucke 2006).

Two main earned value parameters are named the Cost Variance (CV) and the Schedule Variance (SV). They can be calculated with the formulas given;

$$CV = BCWP - ACWP \quad (\text{Equation 3.3.1})$$

$$SV = BCWP - BCWS \quad (\text{Equation 3.3.2})$$

In equation 3.3.1 and 3.3.2, BCWP stands for the Budgeted Cost of the Works Performed while ACWP stands for Actual Costs of Works Performed and BCWS stands for Budgeted Cost of Works Scheduled. These concepts can be explained as follows:

Actual Cost of Works Performed (ACWP) is the real cost incurred to develop the project to its current progress level. The real cost could include all invoices, overheads, and other charges that have been allocated to a specific cost centre within the cost control system. In practice this information is collected from payroll and finance departments of construction companies.

The earned value system incorporates scope and integrates it with cost and schedule. First, the manager determines the value of a project's fully completed or partially completed efforts (consistent with the effort definition above) in the context of the cost that was budgeted and (presumably) agreed upon in the project plans. Only when a specified amount of task work is accomplished does a project earn value, and the amount of that value is determined by the cost that was budgeted (Cioffi 2005).

Budgeted Costs of the Works Performed (BCWP) is the cost value that should have been incurred to bring the project to its current status according to the initial budget of the project. In theory this information is readily available in planning software, if these kinds of applications are used within the organisation. However it is important to note that the amount of work actually achieved on site is not readily available unless it is measured regularly using various classical surveying techniques. Kerzner suggests that the use of short-span work packages or establishment of discrete value milestones within work packages will significantly reduce the work-in-process evaluation problem. This research suggests a different measurement method to address the "accurately and easily measuring the progress" problem.

Budgeted Cost of the Works Scheduled (BCWS) represents the budgeted value of the works that was planned to be achieved according to the works schedule. Planning software contains the data about the works which were planned to be finished to date, and so are the budgeted costs of the planned works.

Therefore the cost variance can be defined as a comparison of how much the work has cost in relation to what it was budgeted to cost, while schedule variance can be defined as a measure of the performance of the works in relation to budgeted costs.

Earned Value calculations also involve the concepts of Budget at Completion (BAC), Estimate at Completion (EAC), and Variance at Completion (VAC).

The budget at completion is the sum of all the individual budgets (BCWS) which make up the project. It is what the project should cost in total to achieve its final level of completion. The estimate at completion is the estimated total cost of the project. It is the sum of all direct and indirect costs to date plus authorised work remaining (EAC = Spent to time + estimate to completion). Some texts recommend that EAC for packages can be considered as:

$$EAC = (ACWP/BCWP) \times BAC \quad (\text{Equation 3.3.3})$$

Variance at completion is the difference between what the job should have cost (BAC) and what it actually will cost (Equation 3.3.4) (Kaka 2003).

EVA parameters can be used to evaluate the project cost monitoring by comparing the values with each others periodically. The evaluation can be made by variances or indexes as suggested below.

Cost Variance: $CV = BCWP - ACWP$

$BCWP > ACWP$ Work performed has cost less than expected

$BCWP < ACWP$ Work performed has cost more than expected

$BCWP = ACWP$ Everything is as planned

Schedule Variance $SV = BCWP - BCWS$

$BCWP > BCWS$ Works ahead of program

BCWP < BCWS	Works behind program
BCWP = BCWS	On programme
Cost Performance Index	$CPI = BCWP / ACWP$
CPI > 1	Good
CPI < 1	Bad
CPI = 1	OK
Schedule Performance Index	$SPI = BCWP / BCWS$
SPI > 1	Good
SPI < 1	Bad
SPI = 1	OK

EVA is a versatile tool commonly used by project managers to control variations as early as possible before they develop into various project failure scenarios. By cost accounting a project manager can take corrective action that will resolve the variation problem within the original budget or justify a new estimate.

While being a useful tool, in practice EVA may fail or misguide project team members due to various reasons. One big reason why EVA may fail is poor estimating techniques, resulting in unrealistic budgets. Another reason why EVA fails is that the project reporting policy available for the management can often be poor. Traditional progress measurement methods are often slow and cost a lot of money. Hence, their frequency is reduced and when they are undertaken, they rely on short cuts and

judgement. Except for unforeseeable technical difficulties, these kinds of problems could be avoided by use of automated processes including those relating to the capture and assessment of progress. Through its proposed methodology this research contributes to progress measurement, hence adding more accurate and frequent EVA.

3.4. S Curves

In order to optimize productivity on new facility construction, the input of resources including men, materials and equipment, is varied according to the planned timing and availability of the work. This applies on all but the smallest construction jobs where minimal crew size may limit flexibility. However, even on quite small "maintenance projects" this flexibility may be facilitated by managing the manpower levels over several concurrent assignments. This optimisation of productivity, results in an initial period of build up, a period of peak loading, followed by a period of progressive demobilizing. This typical profile, or curve, when plotted cumulatively over time for a whole project, results in another typical curve in the shape of the letter "S" (Wideman 1994). In other words, in a well run project, the relation between the cumulative project expenditure and time follows a predictable "S" shaped graphical course.

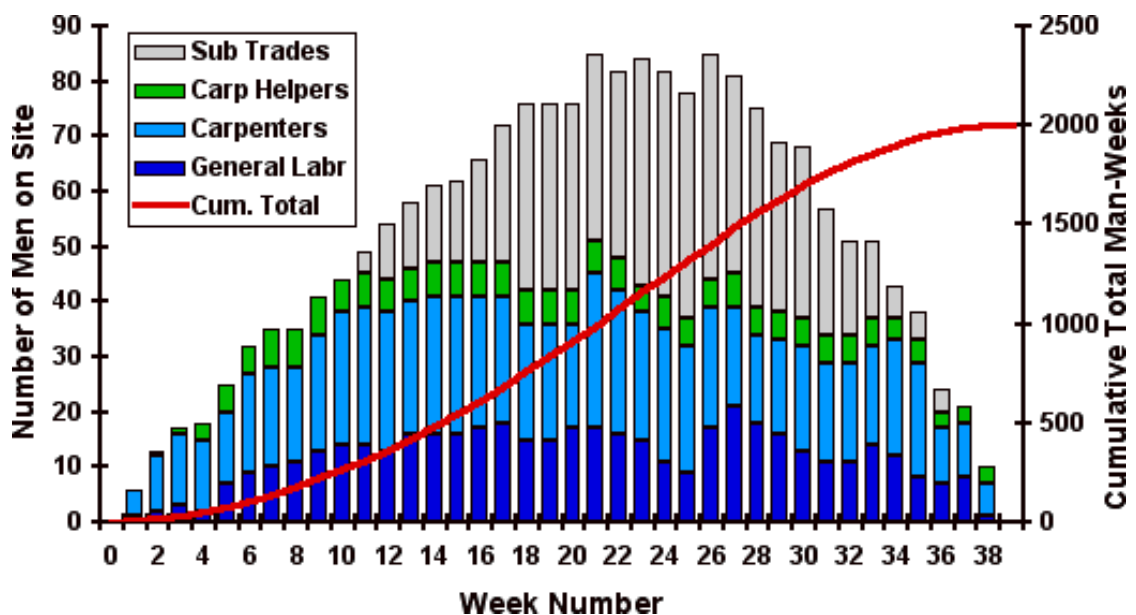


Figure 3.3: An example of how an S-curve develops (Wideman 1994).

It can be observed from figure 3.3 that there are three phases of a typical S curve. Initial part of the curve represents the "build-up" phase. In this phase the work starts from the point zero and becomes available for additional labour to be employed. Necessary preliminary preparatory activities, including planning and understanding local conditions, as well as ordering of materials, etc., often require fewer people but more intensive supervision.

The central part of the curve is relatively "steady-state", or effectively a straight line slope. In this phase the number of labourers reaches to the maximum productivity levels and increasing the numbers would cause them to share same spaces or resources, and, therefore, would be unproductive. Alternatively, if the number of workers on site reduced, this would prolong the completion date of the project, hence would be unproductive.

The latter part of the curve represents a "run-down" which closely mirror-images the early part of the S-curve. This stage is the opposite of the first stage because the available work begins to run out. There is also the effect of some psychological mechanisms as the work comes to the conclusion. The management attention begins to shift to more critical tasks or the worker crews start leaving the site to find employment in more active constructions or less successful personnel start to be let go etc. Also the defective works need to be fixed at this stage without being paid any extra money hence the project team would be extremely unwilling to move forward when the project comes to the end.

A report issued by the National Electrical Contractors Association (NECA) in 1983 further illustrates the general shape of the resource loading S-curve. Data was collected from 40 different contractors on 54 building projects in 32 cities. The projects represented four broad types of public buildings competitively bid and which the contractors felt were typical of their business. The report includes the supporting data which show the ranges of variation. Figure 3.4 shows the overall average manpower consumption rate S-curve for all the data collected. The figure also shows the overall low and high values and it is interesting to note that the range of variation over a

considerable number of projects is only 10% of the total time scale. It should also be noted that a particular condition typically prevails in electrical work on building construction. At the outset, only a small crew is required for installing conduit and other electrical hardware during the course of work by other trades. The bulk of the electrical work cannot be undertaken until those trades are substantially complete. In other words, the work takes longer to open up and accounts for a longer Stage 1 in this particular S-curve (Wideman 1994).

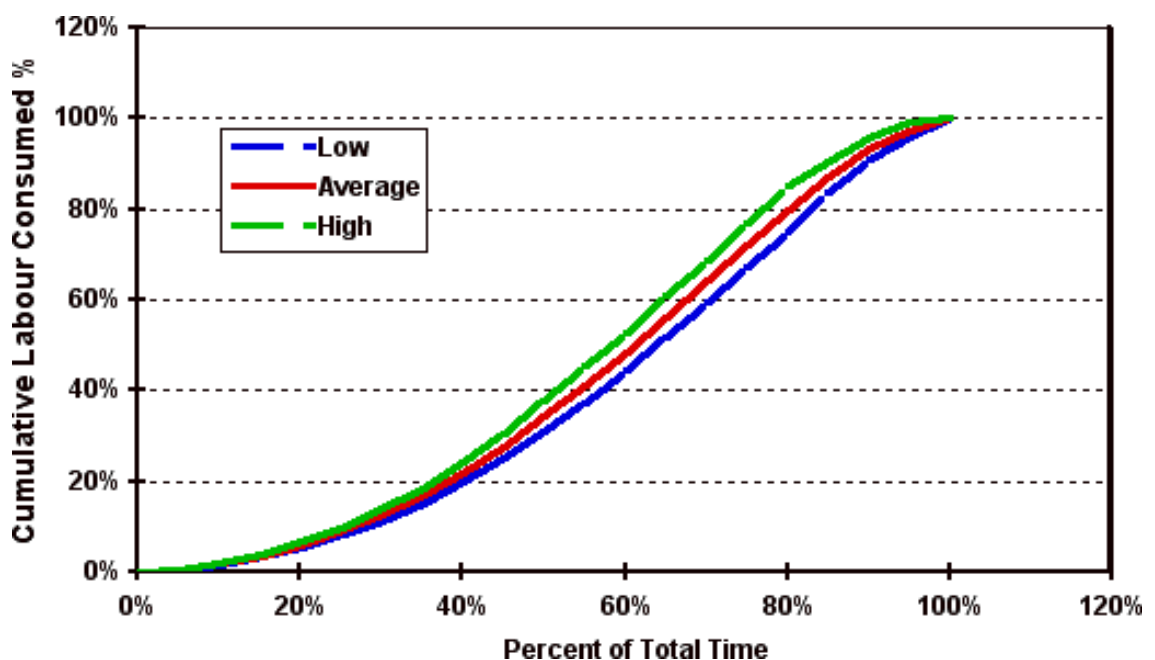


Figure 3.4: Cumulative manpower consumed for electrical systems installation in new buildings (Wideman 1994).

Information so far implies that the s-curve generated throughout the project duration can be used together with EVA. The earned value, i.e. the Budgeted Cost of Work Performed (BCWP), is determined at regular intervals during the course of the project. At the same time, the Actual Cost of Work Performed (ACWP) is also determined, and both are compared to the baseline plan which is the Budgeted Cost of Work Scheduled (BCWS). By presenting these results graphically as S-curves, the variances in cost and schedule can readily be seen, and by analyzing the results relative to the baseline plan

S-curve, estimates can be made of anticipated variations at completion. The key elements of the technique are shown in figure 3.5.

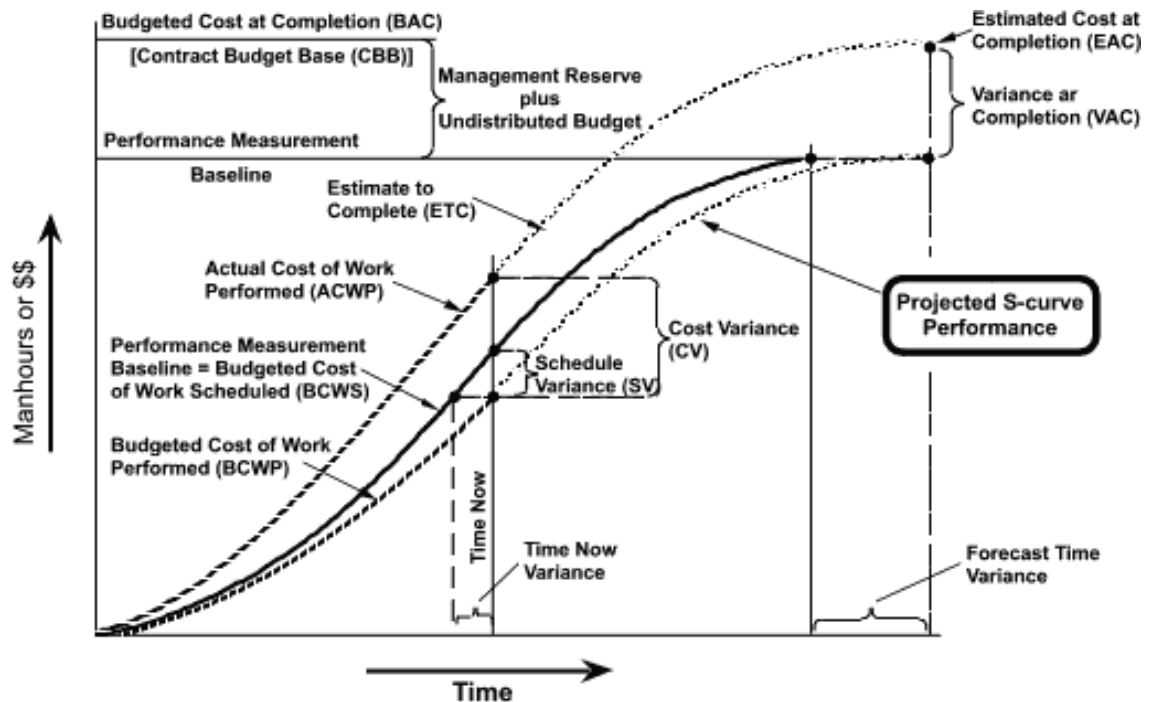


Figure 3.5: Earned value and performance measurement via s-curves (Wideman 1994)

S-curves are not always seen as worth generating by construction companies and project decision makers due to the fact that they rely on estimates about the work completed so far. These estimates must be produced regularly while they are not always easy or cheap to make. The essential element of the technique is a realistically drawn base line s-curve. Inputting the reliable data to the diagram is often a challenge of constant surveying activities. Technique also assumes that all the construction activities are measurable. In its current status technique is only suitable for the big and complex projects where maybe generation of such diagrams is part of contractual documents.

One solution for this problem is to identify the main and critical activities on the project program that are suitable for s-curves and focusing on these elements. One of the main

aims of this research is to suggest a measurement technique to resolve this on-site data collection problem.

3.5. Line of Balance Technique

Line of balance (LOB) is one production scheduling and control technique, which tries to surpass the CPM difficulties for the multi-storey building scheduling. It was developed into a manufacturing environment by the US Navy and had its origins at the time of the World War II. The main concept on LOB is the work continuity of the labour teams over the construction units. The purpose of this technique is to calculate the required resources for each stage of production so that the following stages are not delayed and target output is achieved. The LOB is particularly useful when the deliveries are not linear with time. However, the LOB has not found a lasting popularity mainly due to the widespread availability of CPM commercial software (Mahdi 2002).

The line-of-balance technique is based on the underlying assumption that the rate of production for an activity is uniform. In other words, the production rate of an activity is linear where time is plotted on one axis, usually horizontal, and units or stages of an activity on the vertical axis. The production rate of an activity is the slope of the production line and is expressed in terms of units per time.

This technique emerged from the manufacturing industry where the production rate is nearly uniform. Due to the nature of the Construction industry works, the production rate follows more like an S shaped curve. This aspect of the line of balance technique is one reason why it was not very commonly used within the construction industry.

When a certain type of construction is finished, the gradient of the line of balance for this construction is assumed to be similar with any other construction that follows similar building techniques, specifications, size and function. From this aspect the model relies on the availability of previous comparable data, so that it can be useful. If a contractor has the time-work progress diagram of a housing project consisting of 50 small summerhouses, this diagram can be projected to another similar project consisting

of 150 villas. If the gradient of the new diagram is less than the gradient of the model project during the progress, the new project is considered to be behind the schedule if the model project is taken as the target scenario; therefore, if the gradient of the new project is steeper, the new project is considered to be going faster than the schedule.

In the construction industry, design and build contractors often built similar structures using similar formulated designs. Prefabrication is another area of example where the production can be repetitive. Other than these situations, building industry companies are not always likely to encounter similar production processes repetitive enough to be used for line of balance technique.

Suggested technique within this thesis offers a method to collect data from construction sites concerning the progress achieved on site against the time. The data collected from the sites can be used for the line of balance technique from two possible aspects. Firstly, the required historic data necessary to be used for line of balance technique can be obtained from the digital images periodically taken from the previous projects using the suggested photogrammetry and construction knowledge based method. This data can then be stored in computers to be used as a benchmark for the future projects. Secondly, whenever a similar project starts to be built, new data can be obtained from the new images in order to be compared with the older ones using the suggested method again. Since the product of the suggested method is an excel spreadsheet containing the work progress data, it is ideal to be used to support line of balance technique applications.

3.6. Cash Flow Calculations

For many years, the construction industry has suffered a proportionally higher bankruptcy rate than other industries. One of the major causes of bankruptcy is inadequate cash resources and failure to convince creditors that this inadequacy is only temporary. Moreover, profit margin in this fiercely competitive industry is usually very tight and is exposed to many uncertainties during the construction phase. There is thus a need for contractors in the construction industry to forecast the likely cash-flow profile of each project and understand the risk factors affecting it (Hwee and Tiong 2002).

Accurate cash flow forecasting is essential at the tendering and construction stages for all contractors. It provides contractors with information regarding the amount of capital required, the amount of interest that needs to be paid to support an overdraft, and the evaluation of different tendering strategies.

As the construction progresses, variations in schedule and cost planning occur. These variations create risks for contractors and other project stakeholders. The need for simple and fast techniques in cash flow forecasting has been acknowledged in previous research (Kaka 1996). Therefore the cash flow forecasting techniques emerged. These techniques should follow the construction schedule and the bill of quantities.

During the construction stage, as the variation in schedule and cost calculations emerge, the cash flow forecasts must be updated accordingly. Therefore it is important to provide easy and accurate information about the ongoing work. This information can be provided by the proposed method explained in this thesis. The photogrammetry and construction knowledge based progress measurement method offers up to date information about the progress achieved on site. This information is likely to improve the efficiency of the cash flow calculation updates.

3.7. Conclusions

This chapter outlined the current tools available on the market for the project managers in construction industry.

A review of the available alternatives revealed that there are several very useful and powerful traditional process monitoring tools. Each of the methods used by project managers comes with various benefits. These benefits are, being able to visualise project progress, or being able to detect variations on the project process, or being able to forecast potential success or failure in future targets.

It has been noted that the software available to the construction managers is partially able to automate generation of those forecasts or analyses; however the industry craves

for an integrated solution that can deal with all of these problems together under a single automation solution due to the mentioned data exchange problems.

Another problem detected in this area is, how some of these techniques rely on traditional surveying or statistical forecasting techniques etc., to be able to perform reliably. Data collection from the site is often costly and difficult; therefore companies often abandon the attempts of surveying the progress actually on site, and instead, opt for the less difficult but also less reliable statistical forecasting techniques. In this chapter, it has been suggested that the technique created within this thesis can answer some of the problems. These problems are namely the automation need of some building industry tasks, integration of some independent automation tools, and difficulty of data collection issues mentioned in this chapter.

Chapter 4: Related Problems in the Construction Industry and Main Motives	66
4.1. <i>Introduction</i>	66
4.2. <i>The Inhospitable Nature of a Construction Site</i>	67
4.3. <i>Lack of Up to Date As-Built Information</i>	70
4.4. <i>Construction Conflicts, Reasons and Avoidance</i>	72
4.5. <i>Low Performance of the Construction Industry</i>	74
4.6. <i>Increasing Predictability in Construction</i>	75
4.7. <i>Tackling With Islands of Automation</i>	76
4.8. <i>Need for a Better Surveying Method for Existing Buildings</i>	77
4.9. <i>Knowledge Management</i>	79
4.10. <i>Conclusions</i>	80

Chapter 4: Related Problems in the Construction Industry and Main Motives

4.1. Introduction

This chapter explains the main motives that lead researchers to develop better methods to collect data from the construction sites.

The new construction progress measurement model proposed in this research uses hand held digital cameras for capturing images of construction sites. These cameras do not necessarily have to be highly sophisticated or professionally high-end products. The personnel using these cameras may be from construction related technical disciplines and they do not need to be professional photographers. This chapter explains in details why highly sophisticated, laser based or any other high-tech equipment is not yet suitable to be used in the construction business within the current conditions.

The proposed method manipulates the digital images within the CAD space to extract measurements of the construction elements. These measurements are the most needed data relating to the works performed on the site. During the interim or final payments stages, lack of information about the worth of the work performed to date is one of the most common reasons for construction conflicts. This chapter discusses how this function of the model is likely to resolve or avoid possible and common conflicts within the construction industry.

Currently the construction industry generates documentation out of manually collected data. This data generally cannot easily be transferred to the computer environment; therefore the benefits of automation can not be fully reflected to project management discipline. This chapter explains how the current lack of automation on project management can be remedied by the proposed method developed in this research.

4.2. The Inhospitable Nature of a Construction Site

Construction is an open-air activity. This leaves the work on progress exposed to the risk of interruptions due to adverse weather conditions. People working on-site, as well as materials and plant, are also subject to the adverse conditions. This applies just the same to site management personnel as well. Those people who are required to access the information about work on progress are subject to open air weather conditions sometimes sub-zero temperatures or some desert heat conditions.

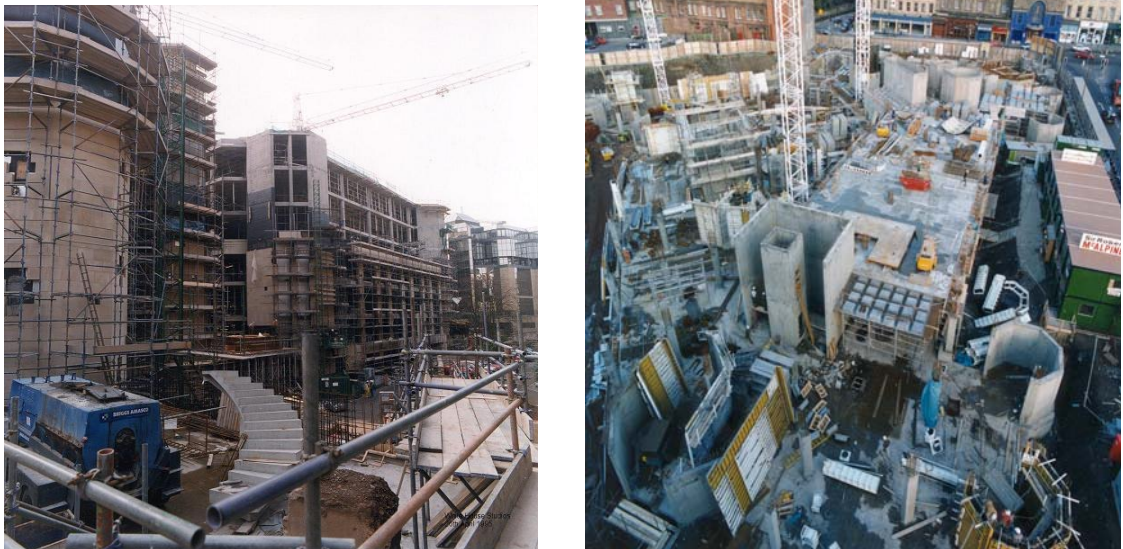


Image 4.1 and 2: Inhospitable and inaccessible nature of construction sites (Haniff 2002).

According to the Health and Safety Executive (HSE), the construction workplace is also one of the most dangerous. In the last 25 years, over 2,800 people have died from injuries they received as a result of construction work. Many more have been injured or made ill (HSE 2007). While it can be argued that the people who are installing the building components on site are always exposed to a certain amount of predictable risks, it is always desirable to reduce the time anyone is under such conditions. This includes the personnel responsible for measuring and reporting on-site progress.

Construction work is often very difficult and dangerous to access for any measurement purposes (see images 4.1, 4.2). Some productions take place in locations up high while others under the ground level. Materials stored on the construction site sometimes make it impossible to access to the work that has been completed. In such cases, using traditional measurement tactics may be impossible; hence construction professionals often resort to less reliable methods like counting the tiles on the ground or bricks on the wall to figure out dimensions of the production and use this kind of data in their documentation.

The aim is to reduce exposure to bad weather and work conditions but it is a major challenge. Still, having an eye on construction site should help slightly. For the partial resolution of this problem fixed cameras can be the way forward.

Illumination level of the construction site is another possible problem confronting the construction professionals. While health and safety executive demands sufficient lighting in work places, it may not always be easy to provide light for one-off needs of measurement activities due to the cost and physical constraints of the work. It is possible to take photos in very low light conditions with or without the aid of camera flash lights. These photos may be low quality due to the grains that appear on image in high ISO values, but they can still be used for photogrammetry based progress measurement. Within smaller distances, flash lights can be used without such image quality problems.

Working on scaffolds has a variety of inherent hazards due to the nature of temporary access structures. In some cases they might be the only option to access the work in progress and using them is often not an option for construction professionals from more managerial backgrounds.

Excavation work is another area that comes with a different variety of difficulties for the industry professionals. The first difficulty is the temporary nature of excavation work. Many trenches on site are excavated and re-filled within hours. This often makes it

Chapter 4

Related problems in the Construction Industry and Main Motives

impossible to measure the work that has been performed to date accurately. Once the trench gets refilled, there is no way of knowing the exact amount of excavation and refill work achieved by a contractor since measurement is totally impossible after that point. Contractors are still paid per cubic meter of excavation and refill they document on their bills of quantities without being controlled by clients. This is a common cause of conflict in construction documentations.

The second set of difficulties about the excavation work monitoring is about the personal injury related hazards. Regardless of the precautions such as various shoring or supporting, excavation sites are dangerous places. Taking measurements of this kind of work is often exclusive to the topography profession since it is so difficult to access to the work that has been achieved so far due to the sheer size of the excavations.

The plant used on sites is a constant danger to professionals. Health and Safety Executive suggest keeping plant and vehicles separate as much as possible, therefore the construction progress monitoring activities are likely to be affected by this. Noise created by the construction plant can make it difficult and hazardous to take measurements as well as personal injury that may happen.

Hazardous materials often constrain the working conditions of progress measurement activities. These materials can be asbestos, flammable or intoxicating materials used on production etc.

Electricity supply installations are an important part of construction activities. In such installations, exposed and live power cables can make it impossible to use any of the traditional progress measurement methods.

Today's hand held digital cameras come with variety of functions and price tags. The picture quality obtained from these cameras is improving dramatically by the day, while their prices are falling. The proposed method in this thesis is applicable to any medium quality digital camera with same amount of accuracy that would be obtained from a

high-end expensive one. These cameras are small enough to be carried by hand without burdening the operator. They are cheap and if they break within the hostile construction environment, that would not strain the project management budget allocated for the job at hand.

The nature of the photography allows the operator to capture information on the work in progress from a considerable distance. This allows a significant safety for the operator considering the risks explained above. The operator can capture high-rise building facades without stepping on to a scaffolding structure or can capture the image of a trench excavation as soon as the operation is finished. The operator is protected from toxic effects of asbestos or any fumes of poisonous chemicals. Inflammable materials can be kept in safe distance throughout the process. Illumination problems of the work place can generally be overcome by the built in flash lights of the cameras as well.

Digital photography offers a quick solution for recording temporary work on-site easily. By means of imaging the trench excavations etc. an operator can keep track of the entire temporary work on site accurately and this information can be extracted by the semi-automatic model proposed within this research.

Digital images captured by these cameras are kept in a memory module and can be previewed as they are recorded. These images are then transferred to a PC easily by means of a simple USB cable and from then they are accessible to all the programs within the network of project members.

4.3. Lack of Up to Date As-Built Information

There is a severe lack of up-to-date as-built information on construction projects (Saidi, Lytle et al. 2003). The absence of real-time information handicaps managers' ability to monitor schedule, cost and other performance indicators, which reduces their ability to detect or manage the variability and uncertainty inherent in project activities (Howell 1999). This state of affairs arises because in building construction, the average duration

of activities is typically in the range of days, while the average frequency of reporting, on the other hand, is monthly (Navon and Sacks 2006).

Mainly there are two type of information necessary to monitor a project's progress. The first set of data is planning and design information and, in theory, these are available at the end of the design stage. The second set of data is about the current state of the construction. This information is not readily available, and the data needed continuously changes. The best way of obtaining this data economically is by capturing it automatically (Navon and Goldschmidt 2003), (Navon 2005), (Navon and Shpatnitsky 2005).

Davidson and Skibniewski reported that with very few exceptions, construction activity is measured using traditional manual data collection, such as supervisors filling in timesheets for workers, collecting paper documentation like delivery notes, etc. (Davidson and Skibniewski 1995). These methods are slow, inaccurate and no longer effective to monitor the current status of the project performance. In a study designed to assess research issues in automated project performance control, it has been reported that some of the information collected this way do not get transferred to a computer environment at all (Navon and Sacks 2006). With manual monitoring, the level of detail of the information that is finally computerised is low. It was found that construction managers have difficulty answering questions such as:

- How many hours were invested in individual building elements?
- What is the general productivity and how is it broken down to elements?
- What are the causes of inactivity (Navon and Sacks 2006)?

Problems identified in these named research works could be avoided with better integration of computers to the progress measurement activities. The data collected on site should be entered in to the computers as soon as it is obtained without any pen and paper based manual calculations involved. The proposed method uses the information extracted from digital images to monitor the construction site status instead of using any

kind of pen and paper based data collection activity. When an operator goes to the construction site and takes a digital snapshot of the work, some data regarding to the progress on-site gets collected by this action. This data is stored initially within the memory of the camera and it is already in digital format. This data is transferred to the PC, and enters into the company network. The moment the digital image enters the computer system is when the information on the image is still unprocessed and raw. However, all the process on these images takes place within the digital environment. Therefore, throughout the process, there is no manual or pen and paper based information re-entry or data transfer. This reduces the labour of data re-entry and also the data becomes more exchangeable between project team members. In addition, the accuracy of construction management activities can be increased due to the benefits of computers. This information can be re-accessed and modified for different purposes as needed.

4.4. Construction Conflicts, Reasons and Avoidance

The construction industry plays a major role in both the economy and infrastructure project delivery worldwide. However, one major critical characteristic of the construction industry is the high cost associated by the resolution of conflicts arising in projects. As a result, project managers are seeking ways to avoid conflicts and resolve them effectively and equitably when they happen (Helen, Pena-Mora et al. 2007).

It is common practice to rely on project managers to resolve disputes after they emerge, however, the best way of minimising the costs involved in conflict resolution must be avoiding the reasons for the conflict in the first place.

Since the construction business is dispute prone (Cheung and Yiu 2005), the reasons for the conflicts are subject to a number of academic research. Some of these reasons why disputes occur are as follows;

- Misunderstandings of documents, conversations;

- Differentiating values and priorities due to culture, education, religion etc.;
- Differentiating interests of contracting parties;
- Different personalities and types of the people involved;
- Former experiences;
- Uniqueness of each construction product;
- Inability of 3D visualisation of people for the projects produced in 2D;
- Changes to the plans and requirements;
- Delays caused by anybody by legitimate or illegitimate reasons;
- Ambiguosness of the definition of product quality.

Some of the factors listed above are directly affected by perception. It is very common that a disagreement emerges over the amount of money to be paid to the contractor. This happens because neither the client nor the contractor often really knows the actual value of the work that has been done to date. Clients are concerned with overmeasurement and paying for work that is yet to be carried out. Contractors on the other hand tend to do their best to be paid promptly, in order to maintain reasonable working capital requirement (Bayrak and Kaka 2005). This dictates the adaptation of more visual enhancement to the construction documentation. Proposed method within this thesis uses digital images to produce 3D snapshots of the construction site. This feature of the model is a potential resolution for the perception related disputes of the construction industry since “Seeing is Believing”.

Another group of conflicts is about inability of people's 3D visualisation for the projects produced in 2D. 2D drawings have potential to create problems on clients from two different aspects. Firstly the construction industry clients are often inexperienced in building procurement activities. This makes them vulnerable to agreeing to projects or contract documentations in 2D against their best interests. This problem is widely addressed by the industry with the introduction of 3D model representations of construction projects. Secondly, interim or final payment documents prepared by contractors contain 2D drawings as supporting attachments. These 2D drawings often make less sense to clients while spreadsheets and pictures of the progress supported with 3D models could be easy to agree upon for anyone.

4.5. Low Performance of the Construction Industry

The construction industry is under-achieving, both in terms of meeting its own needs and those of its clients. Construction in the UK is one of the pillars of the domestic economy. The industry in its widest sense is likely to have an output of some £58 billions in 1998, equivalent to roughly 10% of GDP and employs around 1.4 million people. It is simply too important to be allowed to stagnate (Egan 1998).

Under-achievement can also be found in the growing dissatisfaction with construction among both private and public sector clients. Projects are widely seen as unpredictable in terms of delivery on time, within budget and to the standards of quality expected (Egan 1998).

These problems must be addressed by means of introducing up-to-date technology to the under-achieving processes of the construction industry. One of the main sources of the problem is progress measurement related. Any improvement on the quality of the progress measurement techniques would reduce the unpredictability aspect of the construction endeavours. Buildings can have better chance of being delivered within the budget and on time if the construction progress is better monitored. Such improvements

can consequently improve the client satisfaction and the reputation of the industry in the long run.

4.6. Increasing Predictability in Construction

In a survey made among Singapore's major construction companies, 64% of respondents said that their projects experienced schedule overrun. 34% of respondents suffered at least 10% overrun. 69% of the respondent perceived their projects as having low profit margin. The average profit margin is about 3.75%. The survey shows that about 88% of the projects surveyed have an overall procurement cost at 20% or more of the project value, and about 70% of the projects with procurement cost at 30% or more. For about 23% of the projects surveyed, the procurement cost is more than 50% of the project value (Yeo and Ning 2006). The survey shows the construction industry (in this case Singapore) is unable to deliver projects within the anticipated cost limits. Moreover, the investments are returning with very low profit margins, hence causing growing client dissatisfaction. Proposed technique is an attempt to address this problem by detecting schedule and cost variances in an as early as possible stage.

Automated progress measurement has the potential to tackle the unpredictability problem of the construction industry. Periodically taken digital photos can supply the necessary quantitative data about the progress on-site while this data can be automatically compared with the planning stage data to attain progress deviations. This knowledge is very precious for the project management profession since this information can be used to resolve program variances as early as possible to reduce negative financial consequences. Whatever causes the deviations can easily be detected and tackled within an early phase before it is too late.

If there are good reasons for variances they can be submitted to the client with visual evidence, and new prices or schedules can easily be justified without compromising the reputation of the industry or the company.

4.7. Tackling With Islands of Automation

Another reason of underachievement and unpredictability of the industry is about the fragmentation within the use of automation tools. The use of information technology within the construction industry has seen the isolated development of functional, departmental or organisational solutions. This has resulted in the so called “islands of automation” illustrated by Hannus (Hannus, Penttila et al. 1998).

Ad-hoc development of isolated, function driven, mobile solutions for the construction industry risks the creation of a new archipelago; numerous small islands of solutions that do not feed back or link to existing back-end systems. The solution providers should be aware of this issue and look to provide solutions that can link into a variety of core IT systems e.g. collaboration tools, project models and knowledge management systems. This is imperative, not only to facilitate the uptake of these solutions, but also to gain the maximum benefit from these new sources of information to aid the seamless transition of information and processes between life cycle phases, provide better process understanding, re-use past project knowledge in new developments and achieve process improvement (Bowden, Dorr et al. 2005).

Despite the fact that computer-aided design (CAD) systems are extremely powerful, they are not being utilised thoroughly in the Architecture, Engineering, and Construction (AEC) industries. Specialists in the AEC industries have used today's CAD systems as simply automated drafting tools, thereby automating their own narrow areas of specialisation. Each participant uses unique drafting conventions and their own CAD systems. Information is scattered about the project in an uncontrolled and uncoordinated way, on a variety of information systems and media, so that the design cannot be viewed as a complete entity. Such obstacles to the free flow of information between parties to the construction process lead to data re-entry and the consequent inaccuracies, which prejudice future design 'migration paths' and operational flexibility. These are responsible for many of the quality problems and for adding to the costs of construction projects (Marir, Aouad et al. 1998). These problems dictate more integrated solutions between various computer applications. Data produced on one

application should be able to be transferred to another program seamlessly so that the errors and unnecessary labour can be reduced. The proposed technique integrates the functionalities of office programs with AutoCAD in order to reduce automation fragmentation, so that the quality and the accuracy of the documentation can be improved while the need for data re-entry is overcome.

While computer integration is expected to increase the rate of information exchange, in many cases it actually makes data exchange harder. For each new application, there is a new data format associated with it. Getting different applications to understand each other is a challenge industry has faced in recent years. This problem makes it necessary to avoid creating new varieties of data formats as new solutions for automation are proposed. The model proposed in this thesis uses Microsoft Visual Basic for Applications (VBA) tools to overcome the data exchange problem between VBA-enabled programs.

4.8. Need for a Better Surveying Method for Existing Buildings

Refurbishment works of the existing buildings often require the design drawings of the subject building. When those drawings are lost or inaccessible, a survey of their existing status becomes necessary. For example, when a major retail company rents a city centre building to be converted to a department store, a team of surveyors have to work on the building to produce the drawings of existing status of the building before the actual design works can start. These surveys are often undertaken by using traditional surveying methods. These methods are costly, difficult and slow. The data must be obtained by measuring all the building components, and the results are recorded by pen and paper. The data collected on site, later need to be transferred manually to the computers so that the necessary CAD drawings can be produced. This process of double data entry also causes waste of time and effort. It is likely to happen that once the team takes the measurements on site and starts the drawings in the head office, they get interrupted by realising that more measurements are necessary to continue drawing.

Old buildings under restoration are also subject to be surveyed for various reasons. Sometimes historic conservation institutions may want to measure old buildings and produce 3D models of them in order to capture and record the current status of the monument. Various methods of digital photogrammetry are increasingly becoming popular for these kinds of surveying applications (Plets, Dix et al. 2006), (Yilmaz, Yakar et al. 2007).

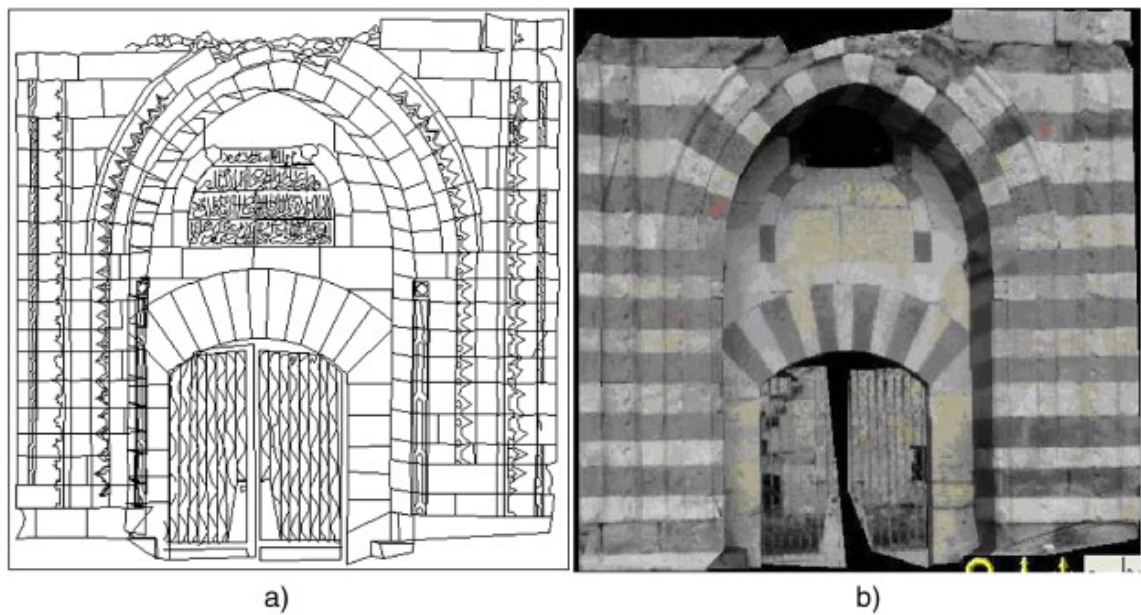


Figure 4.1: “Zazadin Caravansary”, Corolla door in south side. a) 3D drawing, b) 3D model with rendered photo texture (Yilmaz, Yakar et al. 2007).

Example on figure 4.1 shows a surveying application on an old building (Zazadin Caravansary) using a photogrammetry software. 3D drawing in figure 4.1 a, and the texture rendered view of the same drawing in b are both created using the software named PhotoModeler Pro. This example is displayed to show the detail level which can be achieved by photogrammetry applications in surveying.

4.9. Knowledge Management

Among construction life cycles, each stage of construction engineering will rely on a great magnitude of technical and engineering knowledge. To increase operational efficiency, the creation, classification, storage, retrieval, and re-utilisation of the engineering data and knowledge are becoming much more important. Moreover, due to the uniqueness of the construction industry competition, knowledge management has appeared conspicuously attractive. The recent studies have also presented practical examples and beneficiaries for the application of knowledge management in risk management, safety management, design management, facility management and project information management. This trend further emphasises the necessity for the construction industry to apply knowledge management to enhance their competition (Yin, Tserng et al. 2007).

Due to the nature of the construction industry, during the construction stage, data collection for knowledge and the storage of this data is difficult. There is a constant circulation of the personnel. Whenever the need emerges, people are hired and at the end of the project duration they may get fired. Construction companies can not learn enough from the experience gained by these people throughout the project duration when these people leave.

Contractor companies are spending a lot of time and money from the project duration and budget to learn about how to achieve the work to be done; therefore, re-use of this information is very valuable. Effectively collecting and storing the data about the construction processes are the key issues of successful knowledge management. Periodically taken digital images of the construction site associated with spreadsheets and 3D models of the construction site are potentially useful methods of data collection and storage for knowledge management. These series of 3D models, pictures, and the cost data associated to them, can be used to preserve the important knowledge and experience gained through any past project undertaken by the company.

4.10. Conclusions

This chapter outlined the current problems of the construction industry and introduced how photogrammetry and CAD based automation can reduce these problems.

Among these problems, the conflict prone nature of the industry has been discussed together with how the proposed technique can help to reduce the costs incurred due to these conflicts. These conflicts also damage the reputation of the industry badly.

It has been noted that the clients of the industry are widely unsatisfied with the service given to them by the industry. It has been concluded that the proposed progress monitoring method can supply clients with the 3D models of the construction site in progress along with bills of quantities of the work achieved on the site and supported by the images of the work. This variety of information can help clients to understand and accept what they are paying for. This can increase the mutual trust within the contracting parties hence can improve the reputation of the industry while halting the clients common sufferings.

It has been argued that the project managers are lacking up-to-date information about the current stage of the work on the site and they are unable to take corrective measures for the planning variations promptly. It is proposed that the method created within this thesis will reduce this problem greatly by supplying project managers with the data they need to understand schedule and cost variances as early as they occur. This gives them the power to step in and act in good time against the problems by identifying the reasons of the variations much earlier.

The nature of the measurement method proposed in the thesis also improves the health and safety aspect of the measurement activities by giving the operatives the chance to measure progress from a distance without compromising themselves against the common dangers and discomforts of a construction site.

Chapter 4

Related problems in the Construction Industry and Main Motives

It has been reported that the traditional surveying tools are slow and impractical in measuring not only the construction progress but also the buildings to be surveyed for refurbishment purposes. Examples are given to show how photogrammetry can offer an accurate and detailed measurement of buildings to be refurbished.

Experience gained from construction work can often be lost at the end of a contract. Therefore, the re-use of the knowledge or knowledge management became important for contractors. An index or a timeline of the construction activities can be obtained with the proposed method consisting of a series of photos, 3D models and cost spreadsheets. This index of information can be stored in computers to be used for training purposes for the future contracts.

Chapter 5: Methodology	83
5.1. <i>Introduction</i>	83
5.2. <i>Common Types of Research Methodologies Available for Construction</i>	83
5.3. <i>Qualitative vs. Quantitative</i>	84
5.3.1. <i>Qualitative Research</i>	85
5.3.2. <i>Quantitative Research</i>	86
5.4. <i>Data Collection Method Adopted For the Thesis</i>	87
5.5. <i>Conceptual Framework of the Model</i>	89
5.6. <i>Experiments and the Hypothesis to Justify</i>	91
5.7. <i>Ethical Considerations</i>	95
5.8. <i>Strengths of the Method Used</i>	97
5.9. <i>Limitations of the Method Used</i>	99
5.10. <i>Conclusions</i>	100

Chapter 5: Methodology

5.1. Introduction

The effectiveness of data collection is vital to the overall quality of research. That means, poor quality data will lead to poor quality research (Carter and Fortune 2004). Using the correct research method will directly improve the validity and the quality of the research. This chapter is concerned with introducing the research methodology used in this research.

This chapter explains the methods used to create, validate and justify the output of this thesis. After a brief description of available research methodologies for construction, this chapter introduces the subject and structure of the thesis. References to the qualitative and the quantitative research methodologies are made. The scope of the work is also defined and justified. The strengths and the limitations of the proposed method are detailed. The proposed methodology is compared with other similar research works encountered during the literature review.

A summary of the proposed model itself can also be found in this chapter in order to introduce the readers to what was aimed to be achieved with the methodology used in this research.

5.2. Common Types of Research Methodologies Available for Construction

There are various methods to classify research methodologies. Some of the classification approaches can be listed as follows (Fellows and Liu 2003);

- Pure and applied research, where pure research studies focus on the discovery of theories, laws of nature, etc., applied research is directed towards the end user and practical applications.
- Quantitative and Qualitative research; this is the most widely used classification of research and will be discussed in detail in this chapter.

Other than these, further categorisations can be made as follows;

- Instrumental – to construct/calibrate research instruments, whether physical measurement equipment or a test/data collection.
- Descriptive – to identify and record systematically all the elements of a phenomenon, process or system. Such identification and recording is done from a particular perspective and often for a specified purpose.
- Exploratory – to test, or explore aspects of a theory.
- Explanatory – to answer a particular question or explain a specific issue/phenomenon.
- Interpretive – to fit findings/experience to a theoretical framework or model.

5.3. Qualitative vs. Quantitative

In Miles and Huberman's 1994 book *Qualitative Data Analysis*, quantitative researcher Fred Kerlinger is quoted as saying, "There's no such thing as qualitative data. Everything is either 1 or 0" (Miles and Huberman 1994). Another researcher, D. T. Campbell, asserts "all research ultimately has a qualitative grounding". This back and forth banter among qualitative and quantitative researchers is "essentially unproductive"

according to Miles and Huberman. They and many other researchers agree that these two research methods need each other more often than not (Barnes, Conrad et al. 2005). However, because typically qualitative data involves words and quantitative data involves numbers, there are some researchers who feel that one is better (or more scientific) than the other. Another major difference between the two is that qualitative research is inductive and quantitative research is deductive. In qualitative research, a hypothesis is not needed to begin research. However, all quantitative research requires a hypothesis before research can begin (Barnes, Conrad et al. 2005).

Measurement of the physical progress of construction activities by quantities achieved on the construction site so far is a quantitative approach by its nature. While actual application of the model developed within this thesis is mainly quantitative, usefulness, justification or validation process of the research subject sometimes partially falls into the qualitative research path.

5.3.1. Qualitative Research

Qualitative research techniques come in handy when the researchers need to gain insight into problems with complex and controversial issues. Some examples of these controversial subjects would be how people view topics like God and religion, human sexuality, the death penalty, or gun control (Trochim 2006). This method of research is often recommended for earlier stages of research. By qualitative research, the design emerges as the study unfolds. The researcher himself is the data gathering instrument. At this stage, the data is in the form of words, pictures or objects (Neill 2007).

The PhD thesis of this research is the product of a study period of 4 years. During the earlier stages of the work, details of the purpose, methodology and the aims of the work were not very clear. During that stage, the study was rolling around the questions like how the construction industry is applying computer based automation to its procedures, where academia is suggesting improvements and finally where these solutions proposed by academia or developed by the industry can be improved. While this kind of thinking

can be seen as a form of qualitative research technique within a very broad description of qualitative research techniques, the qualitative side of this research is limited to this. This period of the research, led to the revelations of why the construction industry is being seen by its clients as underachieving, or how the conflicts within the construction project team members is leading to industry-wide dissatisfactions. The idea of using computer vision and photogrammetry based methods to create unambiguous measurement methods started to emerge. During the earlier periods of research, it has been identified that academia is mainly concerned with the automation of the planning stage activities. There is a variety of work going on with respect to how planning data can be used together with 3D/ 2D design data, or how to reduce Islands of Automation, but there is very little work going on about how planning variations can be handled during the construction operations. This problem can also be identified as lack of as-built data in the construction industry.

Literature was collected in the form of published papers, books or scientific conference proceedings. The subject areas that needed to be reviewed, in order to be able to develop the necessary model, had to be first identified and the necessary data collected. At the end of this procedure, the information needed to start a quantitative level of a case study was collected. This information then was used to create the proposed semi-automatic, photogrammetry and construction knowledge based method that is the main achievement of this thesis.

Overall, this research is not qualitative based, while in its essence, it does have minor qualitative research elements. Like many other research methodologies used before, it also exploits the benefits of both qualitative and quantitative research methods.

5.3.2. Quantitative Research

The use of quantitative approaches remains predominant within construction management research and this reinforces the idea that the majority of research is still using a rationalist or scientific approach (Carter and Fortune 2004). This is often

attributed to the origins of construction management research lying in the engineering discipline (Edum-Fotwe, Price et al. 1996), (Seymour and Rooke 1995).

With the quantitative research method, the aim is to classify features, count them, and construct statistical models in an attempt to explain what is observed. This type of research is more suitable for the later stages of research. Researchers use tools to measure subjects, and they know what they are looking for in advance. Data collected by this method is in the form of numbers or statistics (Neill 2007).

In this research, the main and final justification is the testing of semi-automatic, photogrammetry and construction knowledge based method developed by means of a Visual Basic for Applications code. This is done by taking digital images at various stages of a construction site and using the developed program to measure quantitative data available on the digital images. These digital images were taken for the purpose of quantitative measurement. The actual measurement tools were a digital camera, a number of commercial software applications and a PC. The products of the measurement process were 3D CAD models of the construction process, the list of quantities, and a spreadsheet of the bills of quantities of the work that was achieved on the site to the date of measurement.

The case study used for the justification of the main theory in this thesis fits mainly into the quantitative research methodology described in this chapter. Main products of the model developed are very quantitative by their nature; therefore the research in this thesis is also quantitative. Due to the quantitative nature of the research, it can also be deduced that the results are fairly conclusive.

5.4. Data Collection Method Adopted For the Thesis

This thesis adopted a two stage data collection method. In the initial stage the research activities were mainly focussed to exploration around the subject (Figure 5.1).

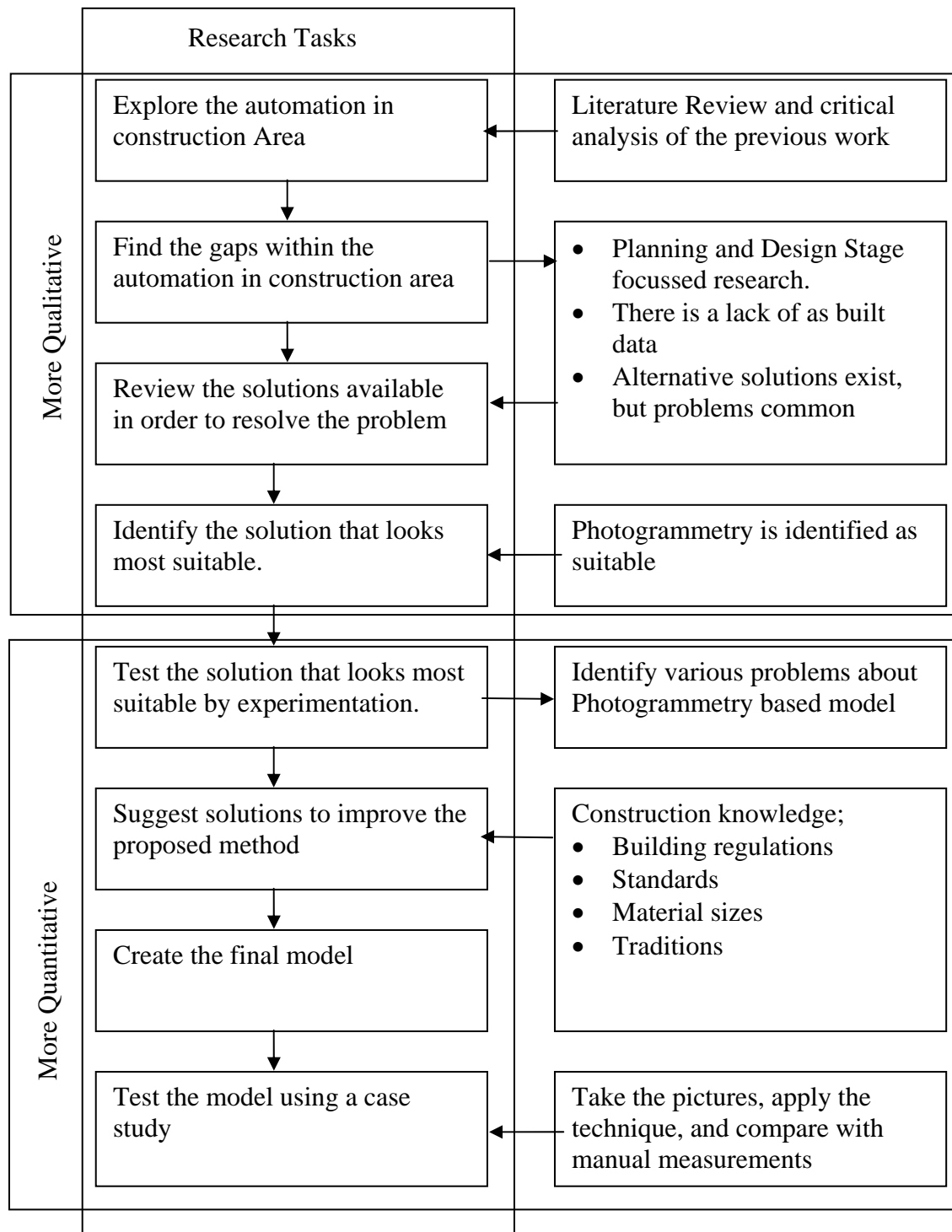


Figure 5.1: Research Strategy

In early stages of the research, after a comprehensive literature review, creating a clear panorama of the automation in construction subject has been aimed. In this panorama it has been identified that the previous work in this area is mainly on planning and design stage activities. Construction progress measurement area is relatively new. In the industry, there is a significant lack of up to date as built data for project managers. There are various alternative solutions being proposed, however there are a number of limitations to each one. Among these solutions, photogrammetry was chosen to be the suitable method; therefore it was tested for further analysis. Until this stage the research methodology is mainly qualitative. The data in this stage is in the form of words, not numbers.

The second stage of the figure 5.1 elaborates activities that are more quantitative. In this stage various automatic measurements were made, these measurements were then compared with manual measurements in order to create meaningful conclusions. The data created at this second stage was in the form of numbers. Limitations and problems with the created model was identified and reported.

5.5. Conceptual Framework of the Model

The thesis proposes a semi-automatic measurement method for construction progress using a combination of construction knowledge, photogrammetry and digital images. The main theory is that the digital images contain enough information required to measure construction progress but the main challenge is in extracting this information in an automated manner.

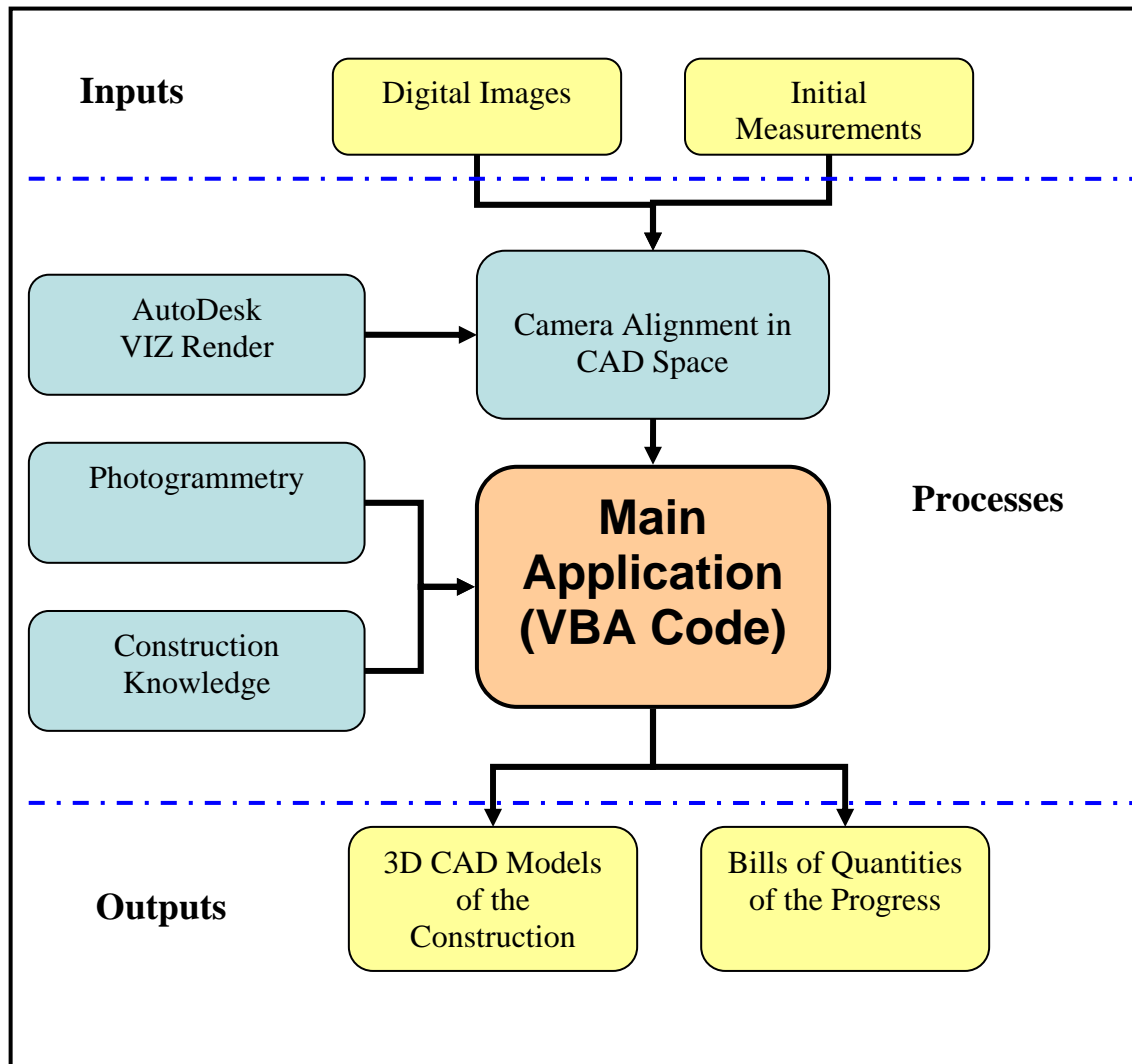


Figure 5.2: Framework of the model

Figure 5.2 explains the framework of the proposed model. The diagram shows that the inputs of the model are Digital images and a small amount of measurements taken from the construction site in order to start the image alignment procedures within the CAD space. 5 points on the site must be measured to start the photogrammetric measurements within the computer space to initiate the measurement sequence. Once the images are aligned with the 3D CAD models, photogrammetric measurements can begin. After that point no more manual measurement is necessary. The second stage of the procedure can start.

The second stage of the model is represented with the area named “processes” on the diagram. At this stage the data on the image can be converted into 3D CAD models and bills of quantities using the VBA application created for this research. This is possible due to the use of Photogrammetry and construction knowledge integrated into the VBA application. Without quitting the application, the operator can measure entire objects visible on the image imported to the CAD space and convert it into a 3D model. Details of these processes can be found in Chapter 8 of this thesis.

As 3D models of the building components emerge within the CAD space, the dimensions of the 3D CAD model can be exported automatically to Excel format bills of quantities tables. At the end of a sequence of measurements, Budgeted Costs of the Works Performed emerges as a sum under the Excel sheet. This document is ready to be used for construction documentation purposes. 3D CAD models of the construction in progress are also readily available for any visualisation purposes. The operator can compare the building elements visible on an image with the CAD model anytime by projecting the rendered image of the model on top of the source digital image so that any omissions and confusions can be resolved.

These 3D models and Excel sheets can be exported to a variety of different programs. The data available on these files can be exchanged by many different applications without causing any additional data exchange limitations.

5.6. Experiments and the Hypothesis to Justify

This is an empirical research. It primarily relies on a case study based on Turkish Construction Industry summerhouse products. In order to centralise the scope of the study, the research started with following two assumptions;

- Firstly, the construction progress under the review of the proposed method only comprises the superstructure level. That means the building elements being measured with the proposed technique are limited to columns, beams, slabs,

reinforced concrete walls and the block walls. Finishing materials or infrastructural building components, or facilities like cooling, heating systems power installations etc. are all excluded from the scope. Invisible construction components like pipes or cables buried under the rendering, walls or floors can not be measured with the proposed method.

- Only the reinforced concrete frame structures are measured and modelled by the technique. The reason behind this filtration is the fact that other construction methods can also be measured and modelled by the same strategy. Using periodically taken digital images, steel frame structures, wood frame structures and masonry walls can also be modelled and measured. This would only inflate the size of the experiment without bringing additional justification. Another reason is that Turkish summerhouses are almost 100 percent made of reinforced concrete frame structures in reality. In various site visits done in the Turkish summer holiday resort of Kusadasi, no construction techniques other than reinforced concrete frame structures were spotted among the construction sites of various summerhouses (see image 5.1 and image 5.2 for two examples of typical construction methods).



Image 5.1: A summerhouse in Kusadasi. Picture shows a very typical sample of a summerhouse from the Kusadasi district.



Image 5.2: Another summerhouse in Kusadasi. Picture shows a different design of a summerhouse from the same district; however the construction technique is exactly the same.

These two pre-assumptions make it possible to constrain the size, number of floors, and construction method so that an operator using the model developed in this research can create the 3D models of the construction snapshots. The 3D CAD models created by the model contain the numeric information about the quantities of the materials used in the construction. Whole the information needed to create 3D models is available on digital images, the information needed for construction cost calculations available on these 3D models. So all one needs to do is to automate the process of taking the information from images and creating the 3D models, and then automate the process of taking the quantities of the building elements from those 3D models and creating bills of quantities. That means the raw data available on digital images are processed to create cost and quantity related data, along with a 3D presentation of the site, which can be compared easily with the digital image being used.

The visual comparison of 3D models with images is important because many construction industry clients are actually from outside the industry and they don't have the skills to follow 2D drawings and construction documentations. However, anyone can visually appreciate and understand 3D representations of the construction progress when it is projected and overlapped with the source image of the site. This benefit of the model is expected to overcome a main conflict area that emerges during the interim payments stage of a construction contract. Clients will know what they are paying for and the contractors will be able to take the true worth of their efforts (Bayrak and Kaka 2005).

In the construction industry, measurements are generally done by traditional surveying techniques. This involves actually going to the site and measuring the building efforts. The second and more important benefit of the proposed technique is the automatic generation of bills of quantities from those photos. The operator using the technique can measure the current level of the construction from the comfort of his or her office instead of traditional surveying methods.

This thesis uses Visual Basic for Applications (VBA) code to automate AutoCAD 2006 Architectural Desktop software in order to create 3D models of the snapshots of the construction and export them to Microsoft Excel spreadsheets in order to create bills of quantities with prices.

The prototype VBA code was developed just for the purpose of this thesis. Once loaded, it can guide the operator to take measurements of the construction elements or offer the standard building elements from drop-down lists.

Since the scope of the constructions are limited to the Turkish construction industry summerhouse villas and reinforced concrete material, the alternative building components offered to the user by the model were reduced to those common building component sizes among the actual buildings in Turkey. This means when a user intends to insert a standard column, he is offered only a few alternatives of dimensions, since the building regulations and functional requirements of the Turkish summerhouses and the specific building material used for the construction gives the building designers only a limited number of column alternatives. The same approach could have been applied to the office buildings in a certain area instead of summer housing, because of the functional and planning related reasons and building regulations, a different sub-set of structural elements would be offered to the user by those dropdown lists; hence the scope was limited to avoid repetitive applications of the same operations. These eliminations done in the creation of the dropdown menus outlines the main construction knowledge based side of this research.

5.7. Ethical Considerations

This research was done in compliance with Heriot-Watt University Research Ethic Guidelines. This guideline outlines the context and standard protocol for the approval of ethical issues. In this guideline there are following items for general ethics consideration (SBE 2007).

- No field of human activity can be considered exempt from ethical concerns. Increased accountability has led to systems of research governance to ensure that research methods and information are open to public scrutiny and can be seen to be subject to the highest ethical standards.
- Research should conform to generally accepted moral and scientific principles. These are:
 1. Obligations to society: - i.e. conforming with responsible, moral and legal practice; maintenance of high scientific standards and impartial assessment and dissemination of findings.
 2. Obligations to funders and employers: - the relationship between researchers, funders, and employer should be clear and balanced without compromise to morality, the law or professional integrity.
 3. Obligations to colleagues: - the maintenance of standards and appropriate professional behaviour with methods, procedures and findings open to review.
- Breaches of these principles include areas of research misconduct such as fabrication, falsification and plagiarism.
- The well being of all involved in research is of central concern in ethical considerations. All staff is therefore obliged to comply with health and safety guidelines and to carry out a risk assessment of the research whatever its nature (e.g. laboratory work, field work, testing subjects etc).

Due to the individual rights concerning privacy, among the photographs used for the measurement purpose in this research thesis, no human subjects exist. During the capture of these photos, site visits were made with health and safety rules compliance and awareness.

5.8. Strengths of the Method Used

This thesis emerged out of a literature analysis to identify the need within academia and industry. After the initial period of reviewing the ongoing research, a few facts started to become clear.

First of all, construction progress measurement is an area with very little automation and whatever automation is available within it is fragmented. There are so called Islands of Automation, and there is a wide scale effort to link those islands via further automation.

This research does not aim to create a method that resolves the Islands of Automation problem, but it avoids adding to the problem by not creating new data formats or information outputs that can not be processed by other computer applications. Outputs of 3D computer models are created in AutoCAD's ".dwg" format. This format can be recognised by a variety of other design and visualisation software, while it still can be saved or exported as drawing exchange (.dxf) formats for further flexibility. If ".dwg" is not directly compatible with a particular application, it may still be possible to use third party software to convert it into a compatible format. Similar flexibility is also available for Excel files. They can also be saved as or exported to another format easily.

Integration of knowledge and solutions created by various disciplines can offer the benefit of all these disciplines together. The tools and solutions created for resolving the different parts of the construction management discipline related problems can be used together by means of research done in computer integration. This is also the preferred method used to contribute to the ongoing study of this research area. Computer vision, digital photography, photogrammetry, CAD modelling, rendering, MS Excel spreadsheets and construction technology knowledge areas were chosen to be integrated for this purpose. The method used has proven to be useful in integrating these subjects and benefiting the strengths of individual areas, together under the same banner. The end product of the research integrated the named solutions and produced a tool that can use digital images to measure construction progress and display the actual occurrences

in 3D as CAD models. The produced 3D models can also be previewed as rendered images during and after the application for visualisation purposes.

A number of researchers have been working to integrate the capacities and powers of CAD models, planning software and virtual reality tools. A literature review reveals that the products of such integrated solutions are generally 4D models. These models use the data produced during the design and planning stage. Such information is often subject to change during the construction works. In order to obtain accurate 4D models, day to day updates must be made to the planning and design information used in the creation of these models. One of the major strengths of the technique used in this research was delivering a method to supply planners' accurate day to day data about the construction under progress.

Initial research identified that the measurements on construction sites are being made by traditional surveying methods. These traditional progress measurement tools are lacking automation and are not practical to monitor budgeted costs of the works performed easily. This research used digital images of the construction in order to measure the day to day progress on site, and therefore; proposed a solution to the continuous data collection problem of project managers.

The route of this research has been to first identify the need within the industry and academia via literature review, then create the necessary model to resolve the identified problems, and then test the model with some real life construction images to see the usefulness of it. Due to the quantitative methods used on the research, the end product has given unambiguous results when it was used within the case study context. Therefore, the justification and usefulness of the product became clear and uncontroversial. The quantitative nature of the work is a major strength of the method used due to the fact that, numbers are naturally comparable, controllable and easily justifiable.

It has been reported many times by various researchers that documentation within the construction industry has been problematic for the clients of the industry. Architects, surveyors and engineers are often producing and pricing their buildings by means of 2D construction drawings namely, plan, sections and elevations. These design products provide a common language between the construction industry professionals. However, it is common to see that the construction industry clients can not make much sense from this type of visualisation, therefore they are often surprised and disappointed by the products they are ultimately provided with. This issue has been identified within the early stages of this research and was a major motivation factor for using computer vision for the purpose of construction documentation. Digital images used for the model provided a valuable convenience for the people with little or no previous experience with the construction business. With the integration of digital photography and 3D CAD models, now people from different backgrounds can understand and agree upon the same documentation. Since the photographs are uncontroversial, they are strong justification materials; therefore the visual aspect of the research product is a positive side of the method used.

5.9. Limitations of the Method Used

The proposed method uses digital images for measurement input. Capturing these images can be possible by visiting the site periodically or setting up video cameras on site at a number of locations. In both situations the amount of data which can be collected by photography is limited to what is visible on the image. This seems like a major problem when the construction site is occluded with trees, scaffolding, or various cars, trucks and plant. With modern digital cameras, taking additional numbers of pictures doesn't introduce additional costs; therefore the occlusion problem can generally be overcome by taking plenty of photos. Excessive amounts of photos can reduce the practicality of the method while bringing in issues such as additional hard disc space and operators time requirements. Overcoming the problem of occlusions on construction sites remains a major problem for any research that utilises computer vision for data collection purposes.

This research project is constrained within the scope of superstructure level works of housing projects in the Turkish construction industry. This means the measurements done with the proposed method is limited to columns, beams, floors and various types of walls. This detail level spans only a very early stage of the construction process. The same construction will then be rendered, installed with electrical, mechanical and water related infrastructure and finished with various cladding and painting materials. Many of these productions are buried within the walls or hidden within shafts inaccessible by cameras. Multiple layers of walls conceal whatever material was used within the previous layers and this makes it impossible to capture enough detail of the site on digital images.

Another problem with the model is in the evaluation method. The proposed method was quantitative; therefore the evaluation of the research used quantitative approaches. Potential users of the proposed model are construction industry professionals and clients technical advisors. Informal telephone interviews have been made with representatives and clients' professional agents of the Turkish construction industry in order to receive feedback about qualitative aspects of the research. The proposed model received favourable comments in terms of practicality, reliability and user friendliness. Industry professionals and clients representatives both agreed that the model has the potential to reduce construction industry conflicts since the documentation created is easy to understand as well as being supported by visual materials such as digital images and 3D building CAD models. However, due to the distance of Turkish industry to UK, the interviews were informal and unstructured. Although the feedback was positive, this situation creates a methodology limitation.

5.10. Conclusions

This chapter explained the methodology used within the thesis. The subject of the thesis is briefly explained and the chapters are introduced. Literature review areas were introduced in order to justify the scope. Main targets and hypothesis of the research were defined. Definition and differences of quantitative and qualitative research techniques are introduced and it has been concluded that both approaches can be

introduced to reinforce a thesis for construction management based research. However; it has been identified that the majority of research being done in the construction management discipline follows quantitative research methods. While the subject of this thesis was considered to be mainly quantitative, earlier stages of the work can be partially recognised as qualitative.

During the making of this thesis Heriot-Watt University School of the Built Environment Ethical Guidelines were strictly adhered to while health and safety considerations were kept in mind.

Finally the strengths and weaknesses of the method used were argued and it was proposed that the model is unambiguous, and tangible, but highly constrained in its functionality.

Chapter 6: Extracting 3D Data from Digital Images	103
6.1. <i>Introduction</i>	<i>103</i>
6.2. <i>Camera Models</i>	<i>104</i>
6.2.1. The Perspective Camera Model	104
6.2.2. The Weak Perspective Camera Model	106
6.3. <i>Camera Parameters</i>	<i>106</i>
6.3.1. Extrinsic Parameters	106
6.3.2. Intrinsic Parameters	108
6.4. <i>Taking Measurements from Images</i>	<i>109</i>
6.4.1. Benefits of Photogrammetry Based Method	117
6.4.2. Problems with the Photogrammetry Based Method	117
6.5. <i>Conclusions</i>	<i>118</i>

Chapter 6: Extracting 3D Data from Digital Images

6.1. Introduction

This chapter explains the scientific facts behind the computer vision and photogrammetry knowledge being employed in this research. It has been noted that nowadays the rapid advancement of digital imaging equipment, with the employment of new and powerful computers with high graphic abilities, has made it feasible to use this technology for digital documentation (Styliadis 2006). Computer hard-discs or server spaces are also growing fast in the volume they can offer while getting cheaper to obtain. This additional space available for reasonable prices makes it possible to store huge amount of video or image files in computer archives.

The purpose of computer vision is to enable a computer to understand its environment from visual information (Shirai 1987). Computer vision is interested in computing properties of a 3D world from one or more digital images. The properties that interest Computer Vision are mainly geometric (Trucco and Verri 1998). Photogrammetry is a field that deals with techniques and processes that allow us to do accurate measurements from photographs and digital imagery. The output can be two-dimensional (2D) or 3D models. In contemporary photogrammetry the main task is drawing accurate 3D graphics (Coltekin 2006).

Computer vision applications have dramatically increased over the past five to ten years. Computer, or ‘machine vision’ as ‘applied computer vision’ is sometimes termed, is now increasingly seen as a key component, often aimed at maximising quality, productivity and efficiency in many automated manufacturing and process control tasks. In addition to the traditional and now well established industrial applications, many new and exciting application areas continue to be explored and developed across a wide range of other disciplines. Examples include innovative applications evolving in nano-technology, surface texture analysis, robotics and reverse engineering (Smith and Smith 2007).

Both the Computer Vision field and Photogrammetry techniques use similar mathematical equations for similar purposes. Computer Vision is aimed at giving perception to computers by means of resolving images as 3D geometric information, while photogrammetry, as used in practice today, is mainly a surveying method using similar techniques to take 3D measurements from digital images.

The knowledge available in Computer Vision and Photogrammetry is potentially very valuable for resolution of construction progress measurement problems. This knowledge offers the benefit of using digital images taken during the construction activities as measurement material for construction progress. Therefore, this chapter outlines the available knowledge within Computer Vision and Photogrammetry areas being used for the research subject of this thesis.

6.2. Camera Models

In computer vision, camera models are defined to compute information from an image. A camera model must be defined first in order to have an approximation to get calculations from photographs. Some of the common camera models are named; the projective, perspective, affine, para-perspective, weak perspective and orthographic cameras (Shapiro 1995). Camera models aim to mathematically model the type of geometrical projection a camera does, so that the relation between the scene and the image can be calculated. In other words camera models mathematically link the images with the 3D scene points. Some of the common camera models can be explained as follows.

6.2.1. The Perspective Camera Model

The most common approximation of a camera projection is known as perspective or pinhole camera model. The model relies on co-linearity assumption about cameras. According to co-linearity rules, at the moment of photo snapshot a point on the scene and the lens centre and the image of the scene point on projection curtain are all in a straight line.

The model consists of a plane π , the image plane, and a 3-D point O, the centre or the focus of projection. The distance between π and O is the focal length (f). Z is the optical axis and the intersection of the optical axis with π is named the principal point or image centre. As seen in figure 6.1, p, the image of P, is the point at which the straight line through P and O intersects the image plane π . Considering the O as the origin of a coordinate system, the following equations of the perspective camera model can be written as shown;

$$x = f X/Z \quad \text{Equation 6.1.}$$

$$y = f Y/Z \quad \text{Equation 6.2.}$$

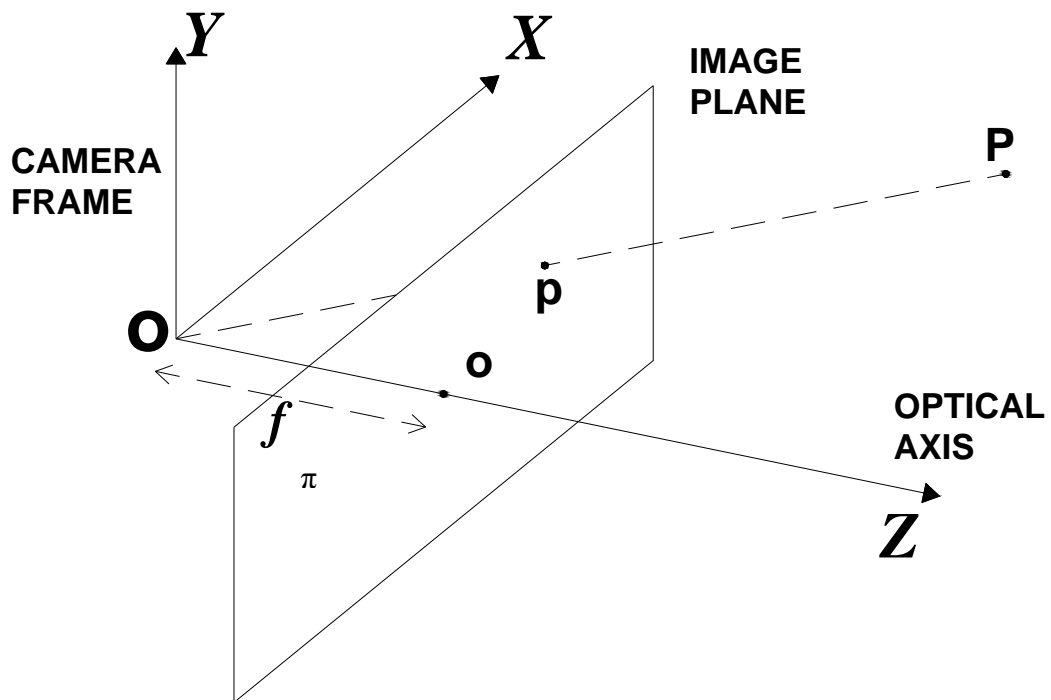


Figure 6.1: The perspective camera model (Trucco and Verri 1998).

It should be noted that the equations in (3.2.1) are non-linear because of the factor $1/Z$ and do not preserve either distances between points, or angles between lines.

6.2.2. The Weak Perspective Camera Model

Because the equations in perspective camera model are non-linear, the weak perspective camera model simplifies them to create linear equations. Model can give approximately right results only when the depth of the scene is much smaller than the average distance of the camera from the scene.

$$x = f X/Z \approx f X/\check{Z} \quad \text{Equation 6.3}$$

$$y = f Y/Z \approx f Y/\check{Z} \quad \text{Equation 6.4}$$

The benefit of the equations 6.3 and 6.4 is the fact that they are linear and easy to resolve. If the Z values on the scene vary a lot, the model gives unreliable results.

6.3. Camera Parameters

Understanding the way a camera works is vital to be able to calculate geometric information from images taken with these cameras. The knowledge necessary to understand the way cameras work is multi-disciplinary. It deals with computers, optics, maths, and geometrics.

The parameters to reconstruct a 3D structure of a scene, or computing the position of objects in space, are explained under this heading. These parameters are known as Extrinsic and Intrinsic parameters of a camera.

6.3.1. Extrinsic Parameters

The extrinsic parameters are the parameters that define the location and orientation of the camera reference frame with respect to a known world reference frame. The camera reference frame is often unknown and a common problem is determining the location and orientation of the camera frame with respect to some known reference frame, using

only image information. The extrinsic parameters are defined as any set of geometric parameters that identify uniquely the transformation between the unknown camera reference frame and a known reference frame, named the world reference frame (Trucco and Verri 1998).

The camera and world frames are transformed to each others by means of a 3D translation vector T , A 3x3 rotation matrix, R . The relation between the coordinates of a point P in the world and camera frame, P_w and P_c respectively, is

$$P_c = R (P_w - T) \quad \text{Equation 6.5}$$

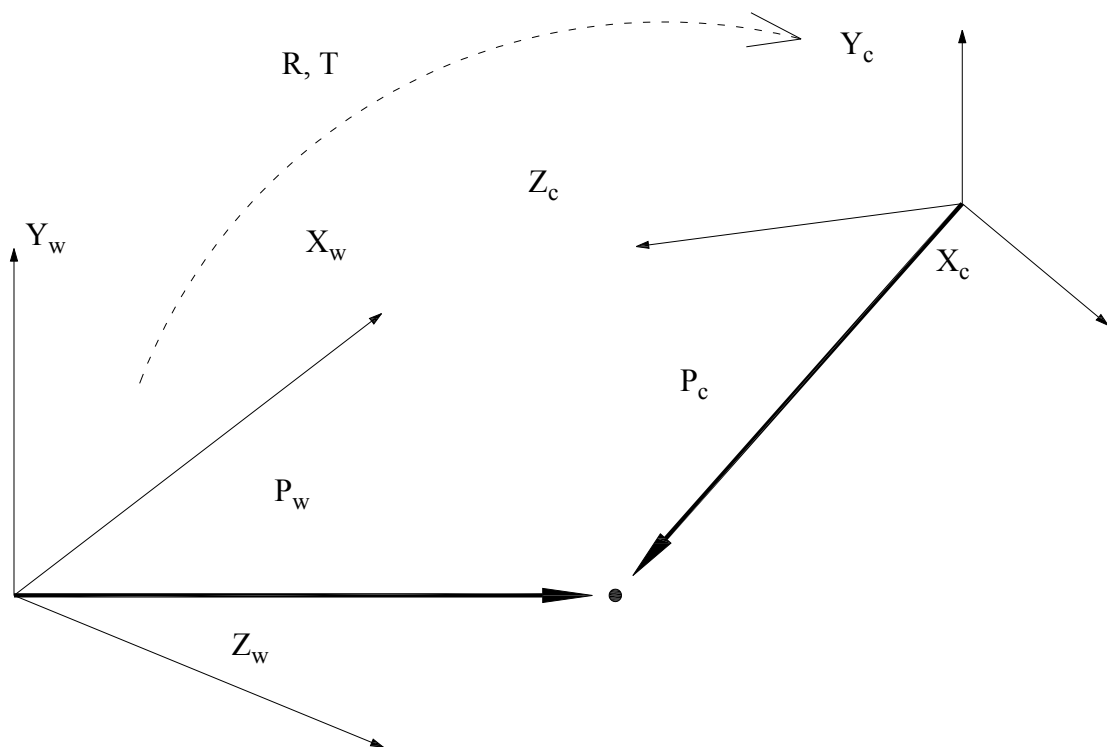


Figure 6.2: The relation between camera and world coordinate frames (Trucco and Verri 1998)

With

$$R = \begin{pmatrix} r11 & r12 & r13 \\ r21 & r22 & r23 \\ r31 & r32 & r33 \end{pmatrix} \quad \text{Equation 6.6}$$

In equation 6.4, the symbols inside the matrix (r) represent trigonometric transformation equations between the coordinate frame of the world and camera.

6.3.2. Intrinsic Parameters

The intrinsic parameters can be defined as the set of parameters needed to characterise the optical, geometric, and digital characteristics of the viewing camera. For a pinhole camera we need three sets of intrinsic parameters, specifying respectively

- The perspective projection, for which the only parameter is the focal length, f;
- The transformation between camera frame coordinates and pixel coordinates;
- The geometric distortion introduced by the optics (Trucco and Verri 1998).

The transformation between camera and image frame coordinates is done as follows;

$$x = -(x_{im} - o_x) s_x \quad \text{Equation 6.7}$$

$$y = -(y_{im} - o_y) s_y \quad \text{Equation 6.8}$$

with (o_x, o_y) are the coordinates of the image centre (principal point), and (s_x, s_y) the effective size of the pixel (in millimetres) in the horizontal and vertical directions.

So far the intrinsic parameters of the camera can be summarised as, f, o_x, o_y, s_x, s_y .

Optical distortions that occur in every camera have been ignored for the simplicity purposes of this research scope. They rarely have a significant effect on the calculations used within the target field of construction progress measurement.

6.4. Taking Measurements from Images

By understanding the basics of camera models and geometric relations between the image and the scene, we can now extract 3D measurements from digital images of construction progress.

To be able to use digital images for measurement purposes in AutoCAD space, these images must be aligned to known building element models to overlap edges and corners of the 3D model and the image. The purpose of this alignment is to mimic the co-linearity situation within the 3D space of AutoCAD. Since the image point, centre of lens and the scene point are co-linear, once a few of the edges of 3D model are aligned with the edges and corners visible on the image, the rest of the edges and corners visible on the image can also be located and generated within the 3D space (Bayrak and Kaka 2005).

Within this research, the alignment process is undertaken by an Autodesk Software called VizRender. This initial alignment requires a minimum of five known points from the construction site. These five points can usually be the corners of the slabs, beams or columns just as long as they are not all co-planar. They must be manually measured only once, during an early stage of the construction. These dimensions can also be taken from 3D or 2D design documents as long as some reliable design document source is available.

Once a simple 3D part of the construction containing these five points are aligned with the image this information is used to mimic the moment of snapshot within AutoCAD Architectural Desktop 3D space.

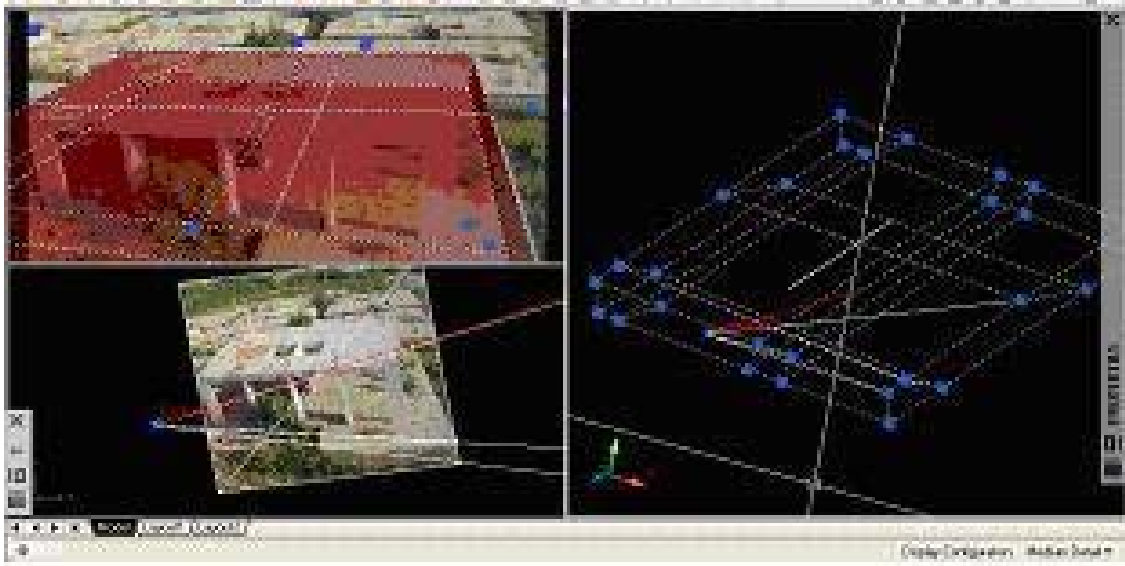


Figure 6.3: Camera Alignment Example1. How a slab visible on the picture can be aligned with a 3D object representing it within AutoCAD.

On figure 6.3 the process of aligning the first construction component with the corresponding digital image is seen. As soon as the alignment is completed, the size of the first 3D object can be compared visually with that seen in the image. Since the camera used within the CAD space mimics the original camera used for taking the image in the first place, the 3D components that have just been aligned with the image will overlap with the image itself correctly if the size of the model is correct. If there are mistakes among the measurements taken on site, or if there are alterations on design projects being used as the source of the information for this alignment, the alignment will either be impossible or any mistake will be spotted by the operator immediately (due to the fact that they will not overlap with the picture). Notice that the rear edge of the foundation level slab is too big and it needs to be trimmed from the back. However, because the alignment has been achieved with the current level of measurements, no

new on-site measurement is necessary. The rear limit of the slab can be detected from the image and the model can be resized to the correct shape as seen on the figure 6.4.



Figure 6.4: Camera Alignment Example 2. Fine-tuning the edges of the foundation slab.

The research has proven that this method could be used to produce 3D models of any building components. This would be possible by detecting the locations of each building element visible on the digital image on the 3D model of foundation level slab. An example of how the columns on the ground floor level located and modelled is seen on the figure 6.5.



Figure 6.5: 3D Modelling with Photogrammetry 1. Ground floor columns complete.



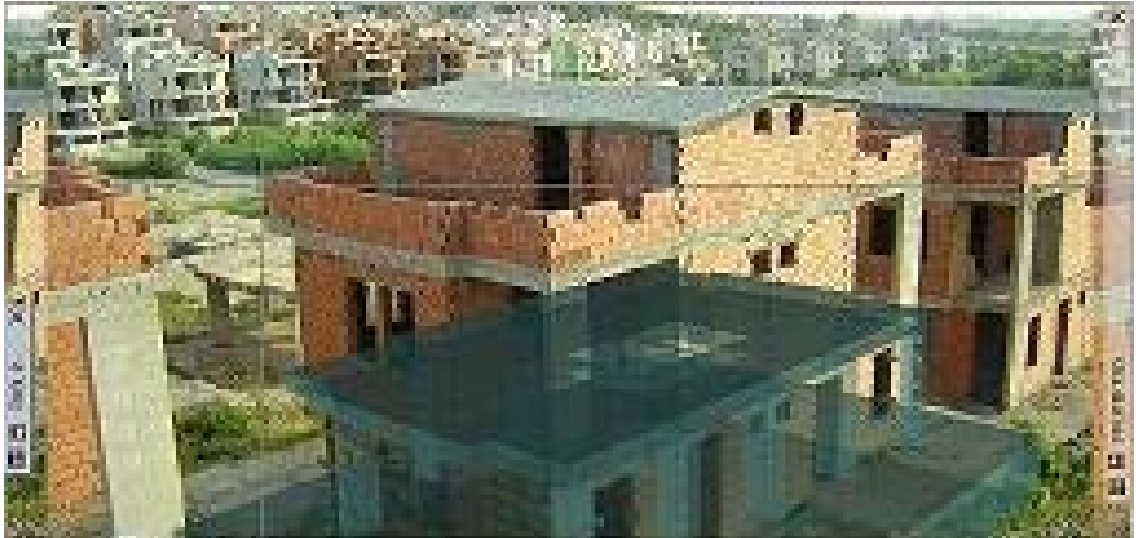
Figure 6.6: 3D Modelling with Photogrammetry 2. First floor slab complete.

After a series of photogrammetric measurements, when the 3D model reaches to the stage demonstrated in figure 6.6, it is clear that the progress on site to the current date has been totally measured. As-built data about the construction is up-to-date. However, the solutions proposed at this stage are not yet suitable for automatic measurement purposes. It takes serious amount of time and effort to create the 3D model of the

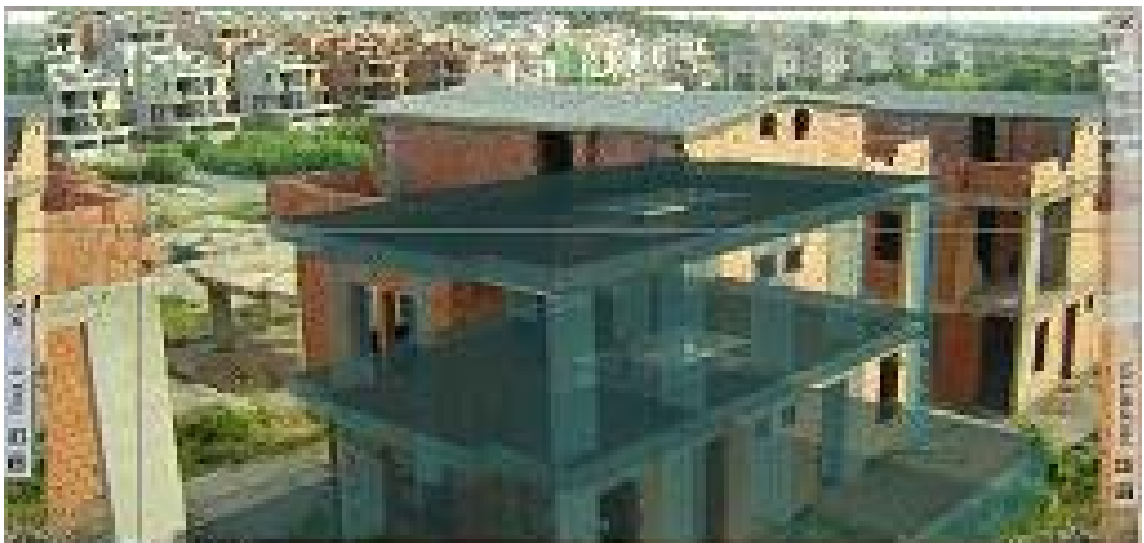
construction. It can be argued that, with this method, using digital images to extract 3D information is not easier than taking measurements from design documentation manually. However, the example shows how the necessary 3D information is available on digital images but the challenge is to extract this data automatically or semi-automatically rather than measuring everything on the picture. In other words, by means of automation, it would be advantageous to get data from images without resorting to intensive manual measurement procedures for creation of 3D models.

Another practical necessity is to export the 3D data created from images to a spreadsheet in order to generate the Bills of Quantities necessary to calculate payments and undertake EVA. An AutoCAD model contains information about the dimensions of the objects created in them, but taking this information out and sorting them into an Excel table is a challenge that needs to be addressed. How this thesis overcomes those challenges and the associated computer automation procedure will be discussed in detail in chapter 8.

When the current stage of construction progress is modelled, new images need to be taken from the construction site to continuously measure the progress on-site as the work on-site advances. This is done periodically and for the new images of the construction, no repeated manual measurement on site is needed for new image alignment with the 3D model. Figure 6.6, a, b, c shows how additional building components are modelled from photos of a more advance stage of the construction. This procedure can sometimes be as simple as copying elements like columns and slabs from one floor to another. In practice, construction activities are very repetitive and this reduces the necessity of repeating the measurement procedures very often.



a. (The same 3D model in image 5.4 is aligned with another image)



b. (Just by copying the first floor, second floor structure is created)



c. (Windows etc. are created by photogrammetry when needed)

Figure 6.7: 3D Modelling with Photogrammetry 3 (a, b, c) How additional building components are modelled using photos of a more advance stage of the construction.

For any stage of the construction process, it is very common that one single image may not contain the whole information needed to accurately model the current stage of the work. In such cases additional images are imported into the AutoCAD space so that the invisible elements from the rear façade of the building for example can also be modelled. The following images show how the 3D model in figure 6.6 can be further processed by importing rear side pictures.



a. (Rear façade of the of the model in figure 6.6)



b. (Walls were inserted and shaped in new model)

Figure 6.8: 3D Modelling with Photogrammetry 4 (a. b). Rear side of the building is modelled from another image.

The process of importing new images to the drawing can be repeated as many times as necessary, depending on the size and complexity of the project at hand. In many small

constructions, one or two images containing only the newly installed building components would be adequate to measure progress, while in larger sites; progress measurement may require a large number of images in order to capture all the necessary details.

6.4.1. Benefits of Photogrammetry Based Method

The proposed model can be seen as a valid means of data collection methods in construction management. Photographs taken during periodic site visits can support the ‘measurement activities’. Automation of the photogrammetric measurement process would help all the contracting parties regardless of their various disciplines to agree and assess the stage of progress at any point in time.

From the excavation level to the end of superstructure construction, there are many temporary works that can never be measured again, or many permanently installed components that are not measured accurately, because of insufficient time of contracting parties or physical difficulties of accessing the details. Temporary structures are built, and demolished, canals are dig and refilled again, without being measured and these ambiguities cause distrust between clients and the construction industry members as mentioned in chapter 4. Digital images record the achievements within the construction site easily even if they are temporary in nature.

Photogrammetry based measurements are much safer than actually spending a long time on-site to measure every detail of the construction under review. Progress achieved on dangerous heights or difficult to access lower grounds, various inaccessible places can still be measured within the comfort of a modern office.

6.4.2. Problems with the Photogrammetry Based Method

Despite the fact that photogrammetry based measurement of construction progress is more comfortable to do than actually measuring everything on site, it is no less time consuming. Without a knowledge based achieve, the proposed model does not add

sufficient value to the project team to warrant investment in it. Solutions for this problem are explained in chapter 8.

A fundamental problem of the proposed system is the lack of details in the evolving 3D CAD models. In fact, it seems only theoretically possible to generate post-superstructure level construction progress results in the 3D model. For example, after generating the 3D models of walls, covering them with plaster and then painting the plastered walls with three (sometimes more) layers of synthetic paint in CAD space are practically unfeasible. Electrical, heating or cooling systems are also very difficult to capture from the incoming images, given that those elements may often be hidden.

Another problem the model has is regarding to the environment which building sites are exposed to. It is often difficult - if not impossible - to take pictures with no obstructions. Scaffoldings, debris, trees or just some vehicles parked on the construction site can block the view of an image, very often from a critical corner. This problem can be avoided to a certain degree if the person who takes the images knows the mentality of the model, since he or she may aim the camera to the most useful angles on the target.

At the current level of research, necessary points on the image are selected manually. Depending on sharpness of the picture or obstruction level, it is often done with some inaccuracies. Although the results of 3D modelling process can be followed from the preview window, there are often mistake margins in dimensions measured reaching up to 5%.

6.5. Conclusions

This chapter explained the multi-disciplinary nature of the computer vision field. It defined mathematical and geometrical concepts behind the computer vision and the photogrammetry.

It is discussed that there are geometrical and mathematical relations linking images with the scenes that were taken. Camera models are used to explain how it is possible to use digital images as measurement tools. When a virtual camera is positioned within the 3D AutoCAD space in order to mimic the image sequence as suggested in the pinhole camera model and the co-linearity rule, the image taken by the original camera can be used to take 3D measurements within the CAD space.

The application of suggested measurement strategies is explained on an example of a summer house building from Turkey. Digital images taken from the different stages of the construction site were used to create the 3D model of the construction progressively. These measurements were done by employing solely the knowledge about the camera models and co-linearity rule of the pinhole camera model. The input of these activities was the digital images of the site taken from various stages and angles of the construction. Five known non-coplanar points were also needed to start the initial alignment and the result was an accurate 3D AutoCAD model of the building as it progressed on site. The 3D model created by the method was supported with images of the construction; therefore it was easy to understand and be agreed upon by all members of the project team. Due to the nature of a CAD model, it contained all the 3D measurements of the construction progress needed by project managers.

The example case study has shown some of the strengths and drawbacks of the photogrammetry based progress measurement method. It is seen that the method is accurate, easy to understand and provides the much needed information about the current stage of the construction safely as needed by the project managers. However it is noted that the suggested method can only 3D model the production visible by cameras. Multi-layer productions can be buried straight away after being made and they cannot practically be modelled with the proposed method. The proposed model is also found to be slow and not ready to offer its information to the operators straight after being produced unless the procedures in it are fully or partially automated. All these identified problems will be addressed within the limits of chapter 8.

Chapter 7: Construction Knowledge Used in this Research 121

7.1.	<i>Introduction</i>	121
7.2.	<i>Structural Columns</i>	123
7.2.1.	Rectangular Columns	123
7.2.2.	Round Columns	126
7.3.	<i>Beams</i>	126
7.3.1.	Wider Beams	127
7.3.2.	Regular Beams	129
7.4.	<i>Floors</i>	131
7.4.1.	Hollow Tile Floor Type	131
7.4.2.	Regular Floors	132
7.5.	<i>Walls</i>	132
7.5.1.	Red Blocks	132
7.5.2.	Autoclaved Aerated Block Walls	134
7.6.	<i>Conclusions</i>	134

Chapter 7: Construction Knowledge Used in this Research

7.1. Introduction

Although photogrammetry based measurement of construction progress is easier than actually measuring everything on site, it is no less time consuming. Without a knowledge based archive, the proposed model does not add sufficient value to the project team to warrant investment in it. Photogrammetry must be accelerated and made more user-friendly in order to be practical for daily progress measurement needs of the project team. Solutions for this problem are explained in this chapter.

This chapter introduces the factors shaping the structural frame and wall layout design of a building at the superstructure level. Within the methodology of this thesis, the extent of the scope of progress measurement task was defined as ‘up to the superstructure level only’. In this chapter the factors such as building regulations, local building traditions, material standards and limitations will be explained. This chapter is not intended as a full guide to reinforced concrete structural design methods. The information covered in this chapter gives only the construction knowledge necessary to create and understand the model proposed by this thesis.

One of the main theories behind this thesis is the fact that the urban texture of a region is partially shaped by various simple factors. For example the texture of Japanese cities is strongly influenced by earthquake regulations. Because of the constant threat of earthquakes the regulations leave much less flexibility to building designers. The Turkish construction industry is also under a similar pressure from the “Regulation for the Buildings within the Disaster Areas”. There are active earthquake zones everywhere within Turkey; therefore, all the structures built in Turkey are subject to this regulation (see Figure 7.1). This regulation deals with various design issues about building

structures such as minimum structural element dimensions or organisation of structures throughout the layout of the building plans.

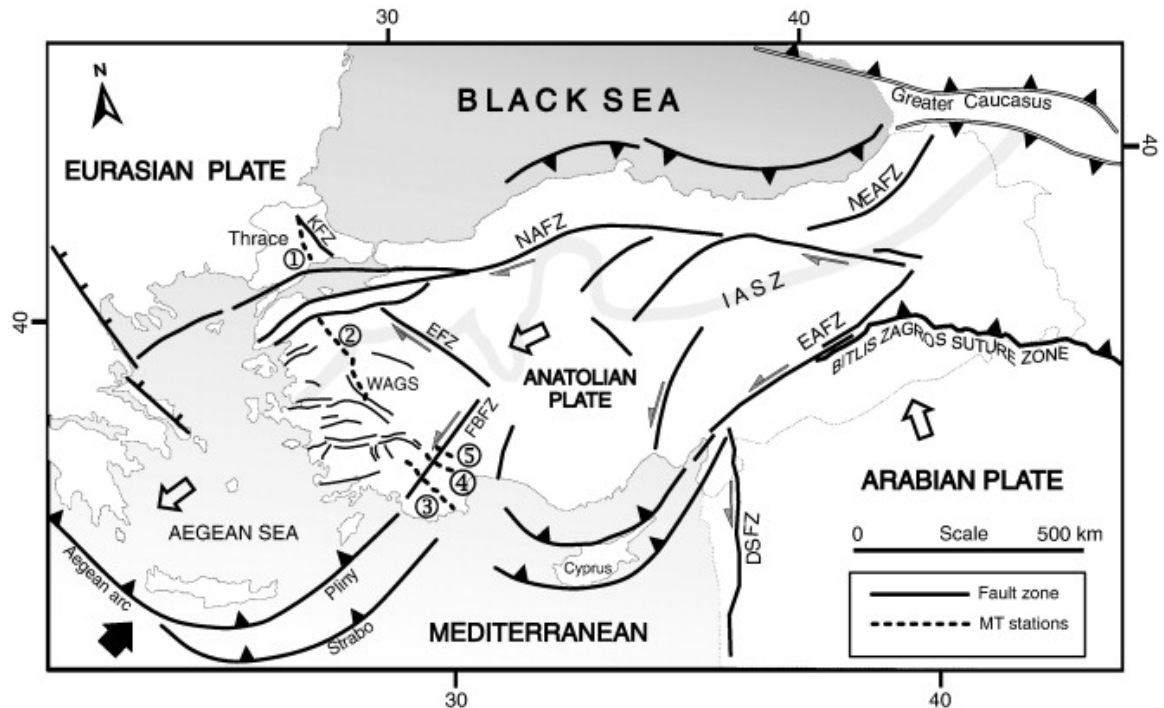


Figure 7.1: Main tectonic elements of Turkey. The map shows that everywhere in Turkey there are active earthquake zones in motion (Gürer and Bayrak 2005).

A large proportion of residential and commercial buildings in Turkey are constructed using reinforced concrete (RC) with masonry infill. Most of this construction is made of in-situ RC beam-column frames with hollow brick infill panels. Partition walls are rarely provided with any structural connection to the structural frame. RC buildings generally have between 3 and 7 storeys and are usually located in urban areas (Bal, Crowley et al. 2006). This chapter will deal with the individual structural elements included in the scope of the construction progress measurement task by introducing the design criteria, material standards and limitations. This knowledge will then be used to resolve problems incurred during the use of this approach, based solely on the photogrammetry and computer vision, covered within chapter 8.

7.2. Structural Columns

Columns are the vertical structural elements loaded in the direction of their axis (Orbay 2005). Columns can be classified using a variety of properties such as material, size, or shape of section. Reinforced concrete columns can take variety of sectional shapes depending on their type. They are generally prismatic shaped (Aka, Keskinel et al. 1990). For the purpose of this thesis, the shape of a column's section is considered to be the main criteria for classification. This is because the proposed method uses 3D CAD models of the structural elements for measurement purposes. The easiest way to create those 3D elements is to extrude them along their axis, using their profile. Since the scope of this research is limited to reinforced concrete housing buildings, the only construction material covered will be that of reinforced concrete. In the Turkish construction industry there are rectangular, cylindrical or various 'T', 'Z', 'U' shaped columns which can be used for structural or architectural reasons. The most commonly used ones are rectangular shaped columns. With the exception of round columns, all other shapes can be produced by uniting rectangular columns together within the CAD space. Therefore, this chapter covers the rectangular and round columns in order to explain the necessary construction knowledge to create the proposed method.

7.2.1. Rectangular Columns

Equation 1 shows the relationship between the column section area (A) and the maximum vertical load. Although the equation is specifying the minimum possible column section, this value can still be used to estimate maximum column section possible within reasonable bounds by estimating the maximum possible vertical load including the earthquake loads (Ndmax). The cylindrical concrete resistance (fck) should be calculated to determine the appropriate concrete type.

$$A > N_{dmax} / (0.5f_{ck}) \quad (\text{equation 1}), (\text{Aydoğanlı 1998})$$

Finding out the missing dimensions of a column, generally involves figuring out one side of the column and estimating the other size through equation 1. The operator can use photogrammetry to calculate one side of the column or can try to use the minimum column size possible by the regulations. By default the shortest dimension a column can take 250 mm since this is the absolute minimum dimension a column can have. For a round column, the minimum allowable diameter is 300 mm.

Due to building regulations and the fact that the buildings within the scope of the research are all 2 storey summer houses, the column sizes are quite consistent within Kusadasi region. In fact throughout the 10 different construction sites visited, all the columns, except one R=300 mm round column, were rectangular. The smaller dimensions of those rectangles were always 200, 250, 300, or 350 mm. The bigger dimensions varied between 400mm to 900mm (see Table 7.1). There are various reasons why these dimension combinations are seen more frequently than others. The first reason is the limitation imposed by earthquake regulations (Aydinoğlu 1998). Previous earthquake regulations stated that the minimum column dimension had to be 200 mm; therefore, the first column contains 200 mm values. These are the current regulations and they will apply to the construction started after 1998. As seen in table 7.1, 33 of the columns observed had 250 mm whilst 30 of them had 200 mm as their width. Other smaller values like 300 and 350 mm widths are much fewer. It can be observed from the table that in the majority of cases, civil engineers choose the column width sizes to be minimum values available on the current regulations. There are 63 columns out of 75 observed on different sites designed using the minimum allowable width values of the current and past building regulations. It accounts to 84 percent of all the observed columns, therefore it is safe to deduct that in Turkey, summer houses of this size category, require no more than minimum values allowed by the regulations to be economical, safe and functional.

	Smaller Dimension (mm)			
	200	250	300	350
Bigger Dimension(mm)	300			
	400			5
	500	18	2	
	600	10	9	
	700	11	2	
	800	9	6	2
	900		1	
	1000			

Table 7.1: Variety of column dimensions sighted among the 10 summer housing sites visited in Kusadasi District.

Figure 7.2 shows the minimum values acceptable for construction projects in Turkey in order to design column sizes according to the current earthquake regulations. Equation 2 determines the minimum size of the other dimension after using 250mm as small dimension.

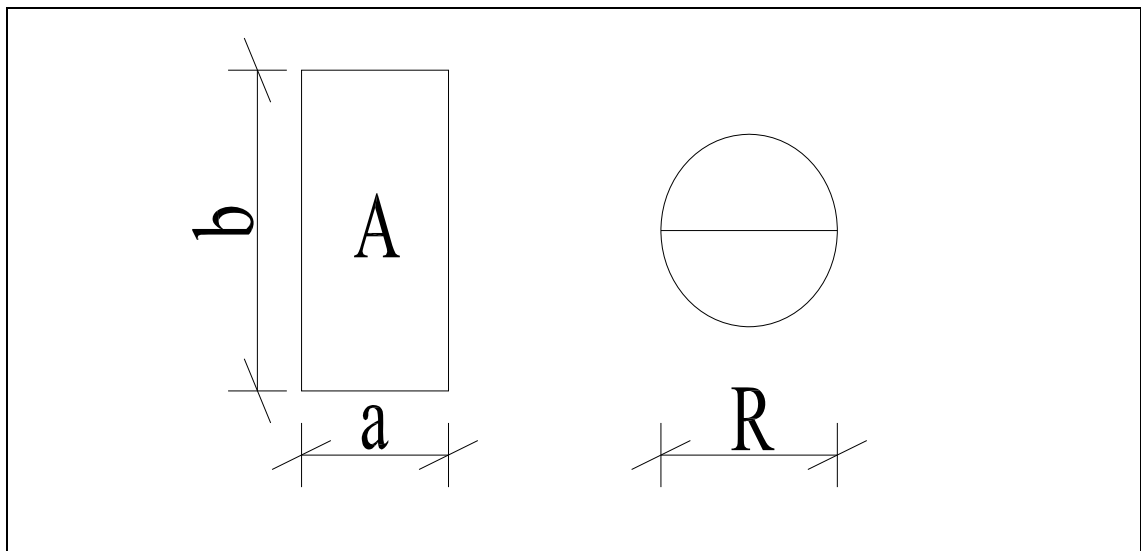


Figure 7.2: Letters representing the dimensional parameters of a column

$$A = a \times b > 75000 \text{ mm}^2 \quad (\text{equations 2), (Aydınoğlu 1998)})$$

$$a > 250 \text{ mm}$$

$$R > 300 \text{ mm}$$

The other reason for small dimensions like 200, or 250mm being popular is due to the block wall thicknesses. When the 200mm columns were legal, the columns were able to be completely concealed by the block walls between them for aesthetical reasons, but now that the minimum size is 250mm, it is only partially possible to hide the columns unless special wall details are adopted since the wall thickness for external block walls is 195 mm.

7.2.2. Round Columns

Current regulations state that the minimum size of a reinforced concrete round (cylindrical) column is $R=300 \text{ mm}$. This rarely occurs but is still worth integrating into the proposed 3D modelling application. Cylindrical columns are used for decorating the facades of the building in partially neo-classical, post-modern architecture, or for aesthetical reasons when a column has to be designed in the middle of a room. Sometimes health and safety concerns can also lead designers to use round columns to avoid the sharp corners of rectangular columns.

7.3. Beams

Again, due to the scope of the thesis, only reinforced concrete beams will be included. Just like columns, beams also have various design criteria and regulations which determine their shape.

The shape of the beam is mainly determined by the type of slab used, the span of the beam and slab thickness. In a mushroom slab, there are no beams at all. These slabs will only have a question of dimensioning the floor thickness. In a hollow tile floor, the tiles determine the thickness of the beam, supporting the floor.

Aesthetics is another reason why a certain beam type is selected. When a designer wishes to hide the beams on the ceiling, without the use of a suspended ceiling, the options are either to use hollow tile floors or to use the regular reinforced concrete beams with minimum horizontal dimension so that they can be hidden within the walls. Therefore, in Turkish housing constructions there are two main types of beams commonly used: wider and regular beams.

7.3.1. Wider Beams

Hollow tile slab type is commonly used when designers want to avoid showing any beams underneath the ceiling. The main beams are created wide, but shallow in order to hide them from sight underneath the floor. Image 7.1 shows an example of how hollow tile floors are formed. The tiles seen on the image are available on the market for various standard sizes and these sizes are the main determinant of the total thickness of the floor and the beam.



Image 7.1: Hollow-tile floor slab under construction (Uyan 2006)

After the initial engineering calculations, the type of the hollow tiles to be used for the floor is selected from the manufacturers' standards. There are six main types of hollow-tiles available on the market with three of them being more common. All six types of tiles are 40 cm wide and 20 cm long. Only the height of the block varies. The most common three heights are 20, 25, and, 30 cm. 22.5, 27.5, and 32.5 cm ones are also available, but these are less common. The various heights on the tiles determine the total thickness of the floor and the height of the beams. After the installation of the blocks and reinforcement, a topping concrete layer is cast. This layer is much slimmer than a regular slab. In practice it is commonly produced at 7 cm, however, the minimum allowable value is 5 cm.

7.3.2. Regular Beams

Regular floor slabs are partially or fully surrounded by rectangular beams. These beams generally have rectangular sections.

There are minimum value formulae for floor thicknesses depending on whether the floor is working in one direction or two, but, since determining the floor thickness is a problem of one single photogrammetric calculation and the plan shape of a slab is generally determined by the beams surrounding it, these formulas will not be needed for the creation of the model proposed in this thesis. Following are the minimum values for the beams;

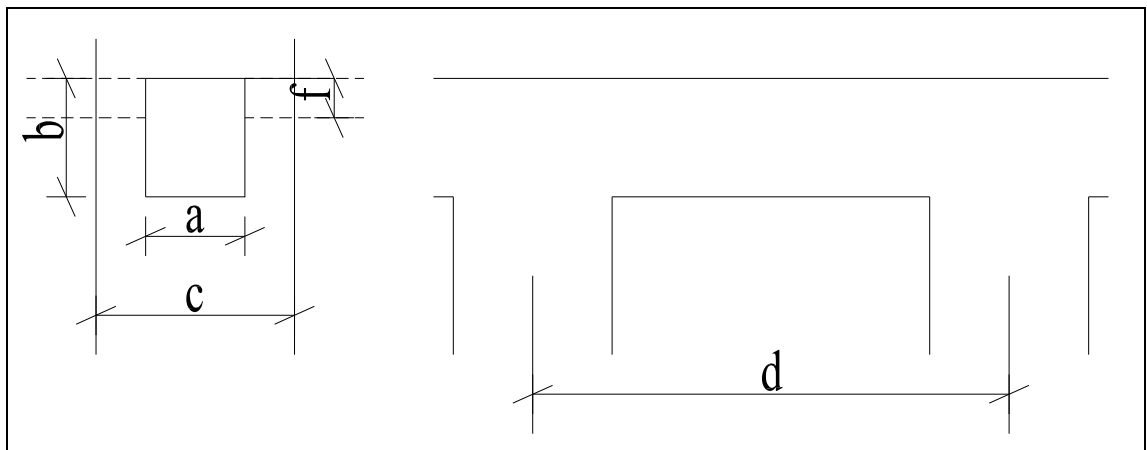


Figure 7.3: Letters representing the dimensional parameters of a beam

$$a > 250 \text{ mm} \quad (\text{equations 5, 6,7,8,9), (Aydinoğlu 1998)}$$

$$b + c > a$$

$$b > 3d$$

$$b < 3.5 \times a$$

$$b < d/4$$



Image 7.2: A villa photo. Regular rectangular reinforced concrete beams produced with 200 mm width, so that they can be concealed by the external walls.

According to the information within the figure 7.3, the minimum width for a beam is 250mm, however, many buildings under construction today had started before the regulations changed, therefore a 200mm beam width is still a common sight within the Turkish construction industry (see image 7.2). After a number of site visits in Kusadasi district of Turkey it has been noted that almost every single summerhouse uses 200 or 250mm beam width, which are the minimum allowable sizes according to the old and new regulations respectively.

7.4. Floors

In reinforced concrete construction products of Turkey, there are two very common types of floors, namely regular slab floors and hollow-tile slab floors. Since they are being cast together with beams and they are supported by beams surrounding them, they are already partially mentioned under beams section. Explanations about the two common types of floors are detailed in the following sections..

7.4.1. Hollow Tile Floor Type

With the exception of few, it is almost certain that the thickness of the slab on tiles is 70mm. The regulations specify the minimum value as 50mm, however, it is advised to use 70mm (Aydınoğlu 1998).

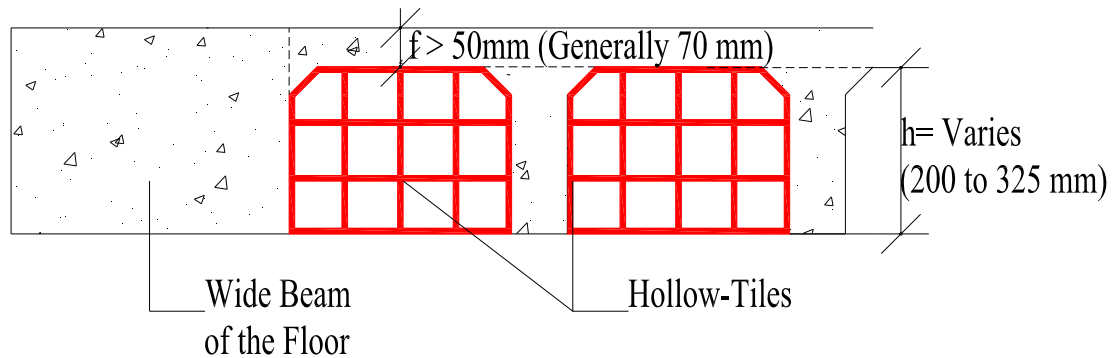


Figure 7.4: Hollow-tile floor type and minimum dimension allowed for the slab are seen.

Figure 7.4 shows that the total thickness of the hollow-tile floor is mainly determined by the size of the hollow-tile used. Length and the width of a hollow-tile floor block are standard and always 200x400 mm. The height (h value on the figure) varies between 200 to 325 mm. The most common modules are 200, 250, and 300 mm.

7.4.2. Regular Floors

Absolute minimum allowable thickness of a floor slab in regular floors is 8 cm. If there are gaps or hollow areas on the slab, the thickness is required to be greater than 15 cm (TSI 2001). Suggested minimum slab thickness in practice is greater than 10 cm.

There are minimum value formulae for floor thicknesses depending on whether the floor is working in one direction or two, but, since determining the floor thickness is a problem of one single photogrammetric calculation and the plan shape of a slab is generally determined by the beams surrounding it, these formulae will not be needed.

7.5. Walls

Walls under this heading are different from reinforced concrete structural walls. Structurally, they are considered totally ineffective during the design calculations. Their sole purpose is to act as separators between rooms and outside space. In theory they only contribute to the architectural shape formation of the building.

For different functions and requirements there are a few common materials that are used in the Turkish construction industry. These are Autoclaved Aerated Block (AAC) walls and regular red brick walls. Both categories are detailed in the following sections.

7.5.1. Red Blocks

In Turkey there are two main types of standard red blocks available. These are 135 x 190 x 190 mm thick blocks or 85 x 190 x 190 mm thick blocks (TSI 2003). The walls created with these two type of blocks can have three different possible thickness sizes; 85 mm, 135 mm, or 195 mm.

An 85 mm block wall is used only for interior separator walls. To improve sound and heat insulation, internal walls can be increased to 135 mm, whilst 190 mm walls are

always either external walls or the walls used between different properties. This knowledge is enough to select from one of the three possible wall thicknesses for an operator using the proposed technique. An experienced operator can also tell the type of block used on a construction immediately by looking at the picture being used by the model.



Image 7.3: A villa. External walls of a summerhouse created out of 135mm regular red bricks.

Some other, very uncommon red block variations are also available. Different factories name them differently but they are often called “isoblocks”. They may have different insulation values and benefits but the important common detail is that, they are used for external walls of a property and their sizes can be either 190 mm or 145 mm thick.

7.5.2. Autoclaved Aerated Block Walls

Autoclaved Aerated Concrete (AAC) is the second common material used in the Turkish housing market to produce walls. AAC blocks come with the standard size of 600 mm x 250 mm. The thickness values start from 75 mm and increase in increments of 25 mm up to 350 mm. AAC blocks are not as common as red bricks but, particularly in colder areas of the country, they are the preferred option due to the better heat insulation performance they can offer. They are also lighter than the regular red bricks; therefore they can be specified for structural weight saving reasons. Although their general performance seems higher than the red bricks, they are harder to cut and shape and also require special equipment for laying. They do not hold on to the rendering layers very well, and finally they are more expensive than the red blocks.

7.6. Conclusions

This chapter introduced the construction knowledge used to create the proposed model. In this chapter, it has been explained that visible physical body of a superstructure level reinforced concrete frame structure consists of walls, floors, beams, and columns. The building regulations and local construction traditions impose the types and the shapes of these structural elements. Manufacturing industry produces the building materials such as bricks and floor blocks in standard sizes. Therefore, it can be seen that knowledge about the design criteria of structural elements or the standard sizes of materials available on the market for construction can be used to create 3D models of the building components. This knowledge on itself may not however be enough to produce 3D CAD models from scratch. However, this knowledge combined with the photogrammetry described in the chapter 6, allows for the creation of semi automatic, photogrammetry based method for progress measurement.

Chapter 8: Proposed Model Explained Using a Case Study 136

8.1.	<i>Introduction</i>	136
8.2.	<i>Loading the Macro</i>	137
8.3.	<i>Running the Macro</i>	138
8.4.	<i>Module Level Events</i>	140
8.5.	<i>The Excel Sheet</i>	140
8.6.	<i>“Main Controls” Control Box</i>	141
8.7.	<i>View Controls</i>	142
8.7.1.	3D Building Model View Button	143
8.7.2.	Digital Image View Button	144
8.7.3.	Preview Button	145
8.8.	<i>Component Editor or “Shape Building Component” Functions</i>	146
8.8.1.	Leave Trace	147
8.8.2.	Abs Distance	148
8.8.3.	Cut Horizontal	149
8.8.4.	Cut Vertical (X)	152
8.8.5.	Cut Vertical (Y)	152
8.8.6.	Subtract Interference	153
8.8.7.	Clean Up	154
8.8.8.	Undo	154
8.8.9.	Rotate 3D	155
8.8.10.	Move	155
8.8.11.	Copy	155
8.9.	<i>Add Building Component Functions</i>	156
8.9.1.	“Add Column” Tab	156
8.9.2.	“Add Beam” Tab	158
8.9.3.	“Add Slab” Tab	160
8.9.4.	“Add Wall” Tab	162
8.10.	<i>“Send to Excel” Buttons</i>	163
8.11.	<i>Conclusions</i>	168

Chapter 8: Proposed Model Explained Using a Case Study

8.1. Introduction

Previously in this thesis, it has been explained that the data collection from a construction site is not an easy process, and the project managers regularly encounter difficulties in gathering as-built information about their work progress. Current surveying methods are not sufficient or feasible to supply project team members with the frequent information they need. There are various conventional progress monitoring tools but they all need a major manual input which can be difficult to obtain. In order to be useful, these methods need the Budgeted Cost of the Works Performed (BCWP) calculated on a regular basis. If this data could be obtained easily, it could be used for progress monitoring techniques such as Earned Value Analysis (EVA), S curve or line of balance. All of these techniques rely on the comparison of BCWP with the actual costs of the work performed or budgeted costs of the work scheduled.

This thesis was written to introduce a method to calculate BCWP in away which is both fast and accurate. The model suggests a computer program which uses a combination of photogrammetry and computer vision techniques together with construction knowledge. The code which was written in Visual Basic for Applications, acts as the main interface of the method application. The code also serves as the main experiment of this thesis.

This chapter serves as a step by step guide to this code. The code was intended as a prototype to show how the proposed model can measure progress in a way which meets the requirements of a real construction activity. It takes the user from the point when the image is loaded into the CAD space to the point where the current budgeted costs of the works performed is presented on an Excel spreadsheet. The user inserts an image of the construction site when an interim or final payment needs to be calculated to the AutoCAD ADT space. An AutoCAD camera is located relatively to the known parts of

the construction model in order to mimic the moment of snapshot. This orientation is done through the use of an Autodesk program called VizRender. VizRender needs five known non-coplanar points from the image to locate and mimic the position of the camera. This information is available on the foundation level model of the building. Therefore the foundation model of the construction is also required as an input too. The rest of the process is described in the following sections.

8.2. Loading the Macro

The code of the proposed application is written in AutoCAD Visual Basic for Applications (VBA). From the “CAD Manager” menu of the AutoCAD, the macro must be browsed, found and loaded to the open AutoCAD session. Once the loading procedure is complete, the macro can be initiated (McFedries 2004), (Clark 2002), (Sutphin 2004). Figure 8.1 shows the “Load Project” menu and its contents. In the current example the project named “Main Controls.dvb” must be loaded.

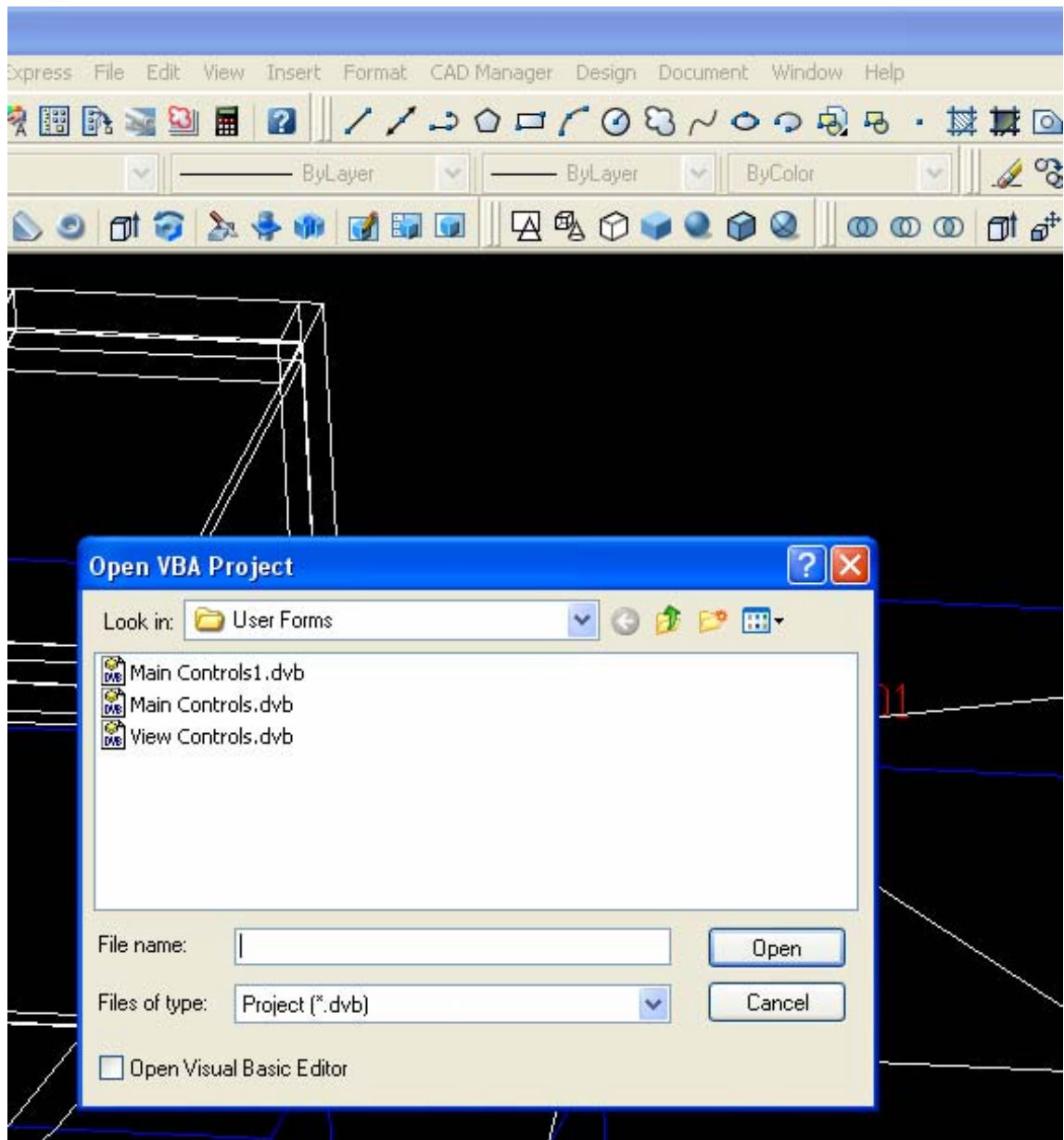


Figure 8.1: Load Project Menu

8.3. Running the Macro

Under the AutoCAD's "Cad Manager" menu, from the "Macros" command, the list of the loaded macros can be viewed. The macro that needs to be run can be selected and executed from this chart by the use of the "Run" button. The appearance of the Macros

chart can be seen in the figure 8.2. The name of the macro to start in this case study is “Main Controls.dvb”.

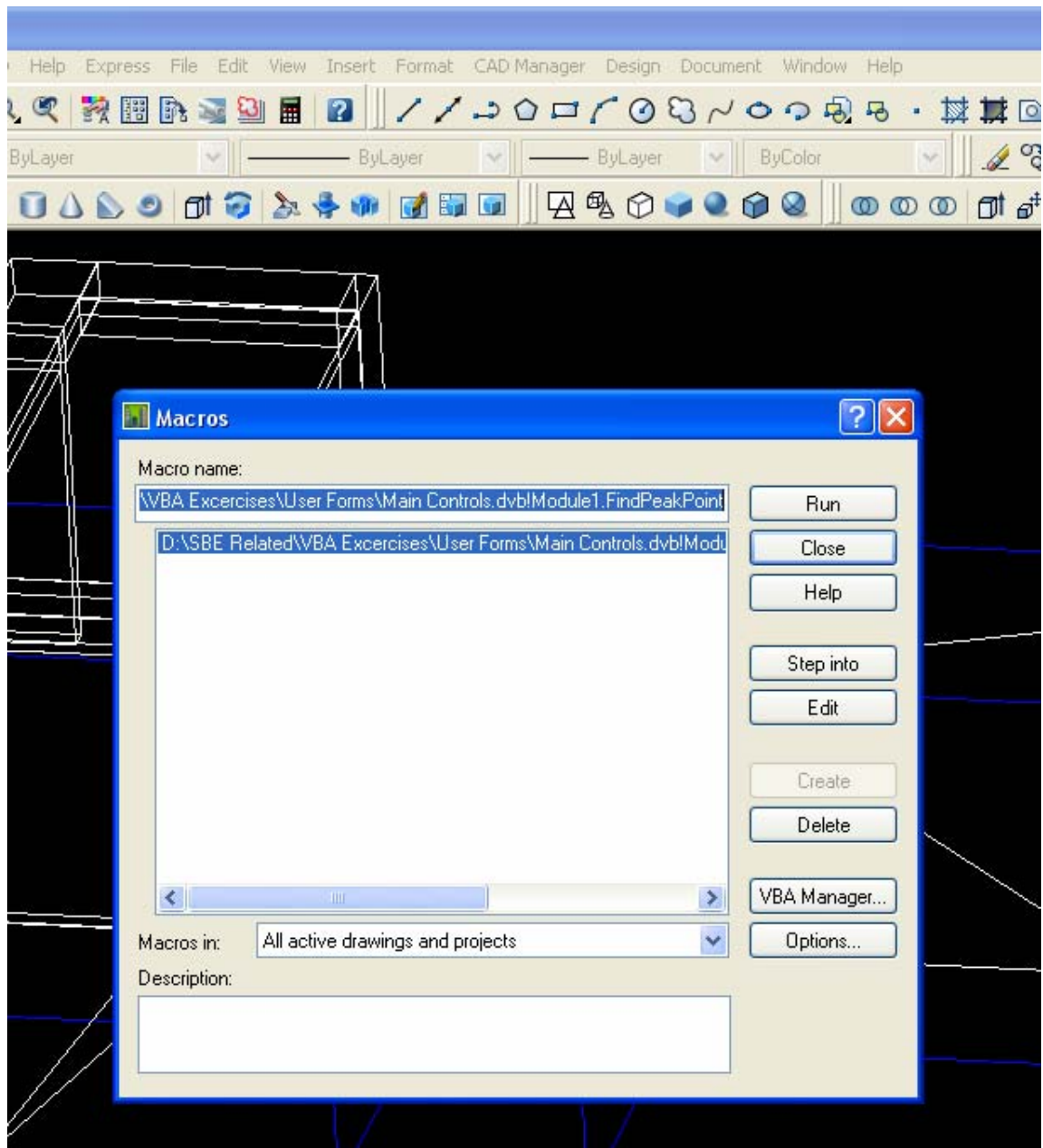


Figure 8.2: Macros chart

When the macro is executed, it starts running by following module level events written in the code.

8.4. Module Level Events

The code itself consists of many sub procedures, but only one module. In every sub procedure there is a number of variables defined, but these sub procedure level variables are only accessible through the sub procedures in which they are defined. Therefore, the variables that need to be reused must be defined in the module level.

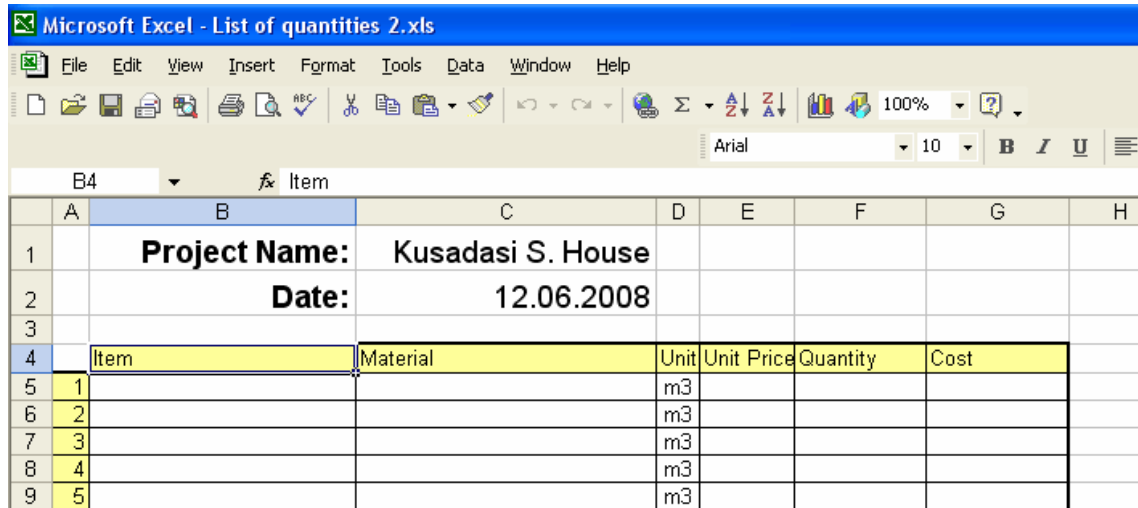
When the macro is executed, the user is asked to provide some inputs. These inputs will be re-used automatically by the code during the runtime whenever they are needed. The first input to be entered is the focal point of the image. Using this input, the code then makes photogrammetric calculations which are explained in this chapter under the “Leave Trace”, “Cut Horizontally”, “Cut Vertically (X)” and the “Cut Vertically (Y)” sections.

The second and third inputs a user is asked to enter are the “Project Name” and the “Interim or Final Payment Date” respectively. These inputs are automatically entered into the top section of the Excel spreadsheet created by the code.

Other than these visible assignments, the code also starts the Excel application in the background and populates the dropdown lists (combo boxes) that exist within the “Main Controls” control box.

8.5. The Excel Sheet

As soon as the user inputs the “Project Name” and the interim or final “Payment Date” entries, the Excel application starts in the background and appears in system tray as a minimised application. The user can maximise it whenever it is needed visually. Later in the case study 3D objects will be exported to the Excel spreadsheet automatically in order to create complete bills of quantities. Figure 8.3 shows the top section of the Excel spreadsheet after the “Project Name” and the “Interim or Final Payment Date” inputs are entered.



	A	B	C	D	E	F	G	H
1		Project Name:	Kusadasi S. House					
2		Date:	12.06.2008					
3								
4		Item	Material	Unit	Unit Price	Quantity	Cost	
5	1			m3				
6	2			m3				
7	3			m3				
8	4			m3				
9	5			m3				

Figure 8.3: The top section of the Excel spreadsheet created by the code at the beginning of the application

8.6. “Main Controls” Control Box

The “Main Controls” control box is the user interface of the application created with VBA (figure 8.4). Once the application is loaded and executed, a floating chart emerges. This floating chart can be located freely anywhere on the screen, so that it doesn’t conceal the drawing area.

The Main Controls chart consists of three groups of tools. The first group of tools is the “View Controls”, the second group is the “Shape Building Component” tools and the final one is the “Add Building Component” tools. Each of these tool groups are explained with their functions in the following sections.

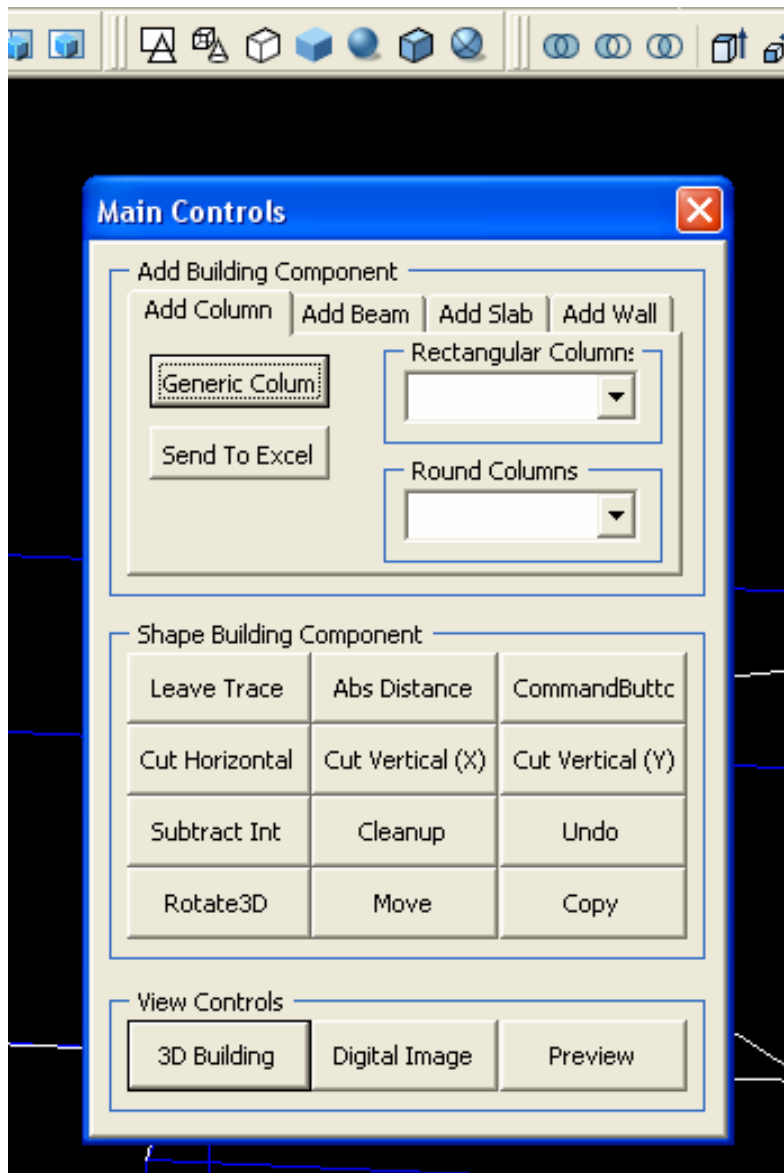


Figure 8.4: “Main Controls” control box as the main user interface of the application

8.7. View Controls

In the majority of AutoCAD 3D modelling applications, an operator can change the direction of the view to be able to see the model from various angles to suit his or her needs. Similarly the User Coordinate System (UCS) can be changed to suit the operator’s momentary needs. These operations are normally achieved by following standard AutoCAD procedures. AutoCAD offers various ways to set UCS’s and view

points. To adjust these settings to suit his or her needs, the operator has to select from wide amount of submenus. View Controls toolbox was integrated to resolve this problem. It simplifies the process of view and UCS selection.

In computer vision, the translation between the cameras coordinate system and the world coordinate system is a common problem to resolve. The proposed model requires switching between two coordinate systems quite often. As mentioned within chapter 6, the photogrammetry based approach requires taking the measurements from the images, whilst creating the 3D model within a different coordinate system. In addition to that, the model and the image need to be visually compared with each other from time to time. For each of these functions there are three function buttons assigned to the application. Each of them represents a preset UCS and view setting. These functions were developed specifically to make the application more user-friendly. Each function automatically adjusts the camera and UCS settings between 3 necessary options. They are located at the bottom of the “Main Controls” control box. The automation procedures and the functions of each button are explained in the following sections. The code used to create these functions in this application can be seen in the Appendix 1.

8.7.1. 3D Building Model View Button

In the 3D Building view, the camera is set to an isometric projection over the 3D model of the construction. The drawings active space property is set to AutoCAD’s model space. The model space is where the 3D or 2D drawing activities take place within the AutoCAD. UCS settings are set in order to make X and Y coordinates to be parallel to the floor of the construction.

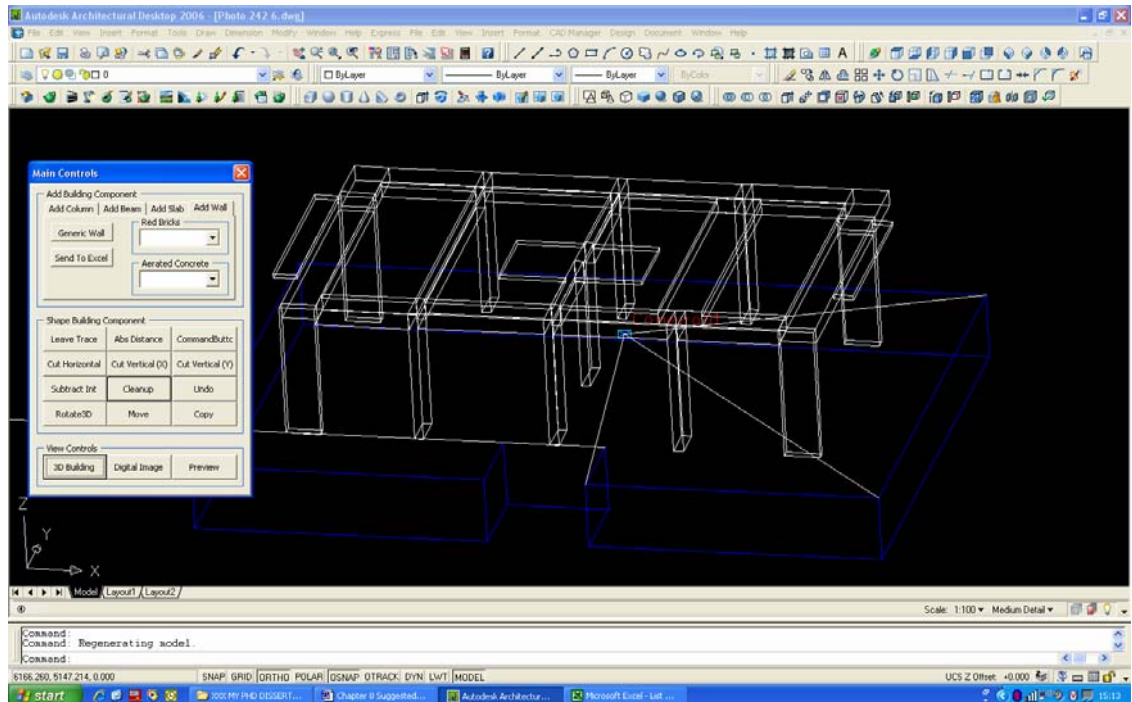


Figure 8.5: An example of “3D Building” view setting

Through these settings the user can generate models parallel or perpendicular to the floor, although the information is projected from a non-parallel UCS (picture’s UCS). While the measurements are taken from a different UCS, the models are generated correctly oriented to the building UCS. Creating these setting manually, using AutoCAD’s built-in menus would be very time consuming, and would make the application unpractical. In the lower left corner of the figure 8.5, it can be seen that the coordinates of the UCS icon is parallel to the floor and the columns.

8.7.2. Digital Image View Button

The digital image view button is simply a plan view, where the source image is in the middle of the screen. The UCS is set to the World Coordinate System which is parallel to the image (not to the 3D model). Again, the drawings active space property is set to “acModelSpace”. The “acModelSpace” is the name given to the active model space of the AUTOCAD in VBA programming language.

Chapter 8

Proposed Method Explained Using a Case Study

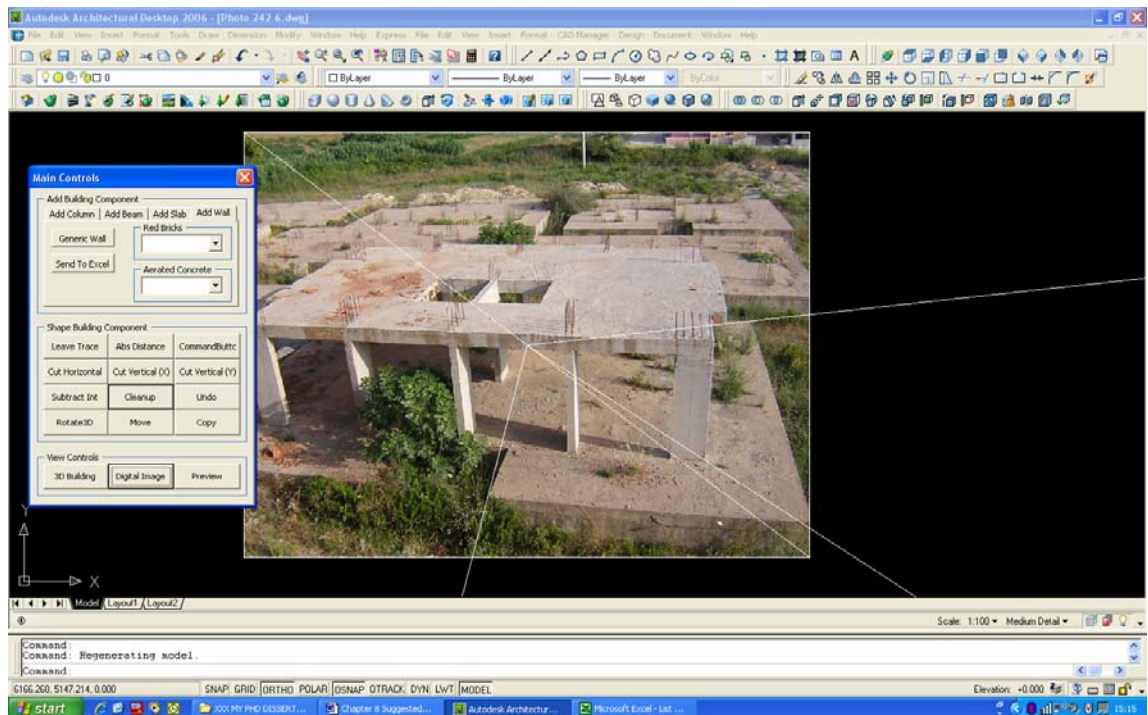


Figure 8.6: An example of the “Digital Image” view setting

The view in the figure 8.6 is set to assist user in deriving the correct photogrammetric measurements from the image. The picture is relatively small when compared to the building components and it is not parallel or oriented to the floor of the building in any way due to the fact that the camera is hand held, and the snapshot was taken from a random point in the space. Due to the co-linearity rule explained in chapter 6 image point, focal point and the object point within the scenery are all collinear (figure 8.8). By switching between the image view and the 3D building view, the user can exploit the co-linearity rule of computer vision and create accurate 3D models of the building, by using the other tools offered in this application.

8.7.3. Preview Button

The preview button renders the AutoCAD view port in order to mimic the image snapshot sequence. In this rendered image, the user can see the progress of 3D modelling s/he has achieved so far. If there are any mistakes in the measurements, the

image in the background and the 3D model in the foreground would not overlap. The example in Figure 8.7 overlaps accurately enough for the measurement purpose.

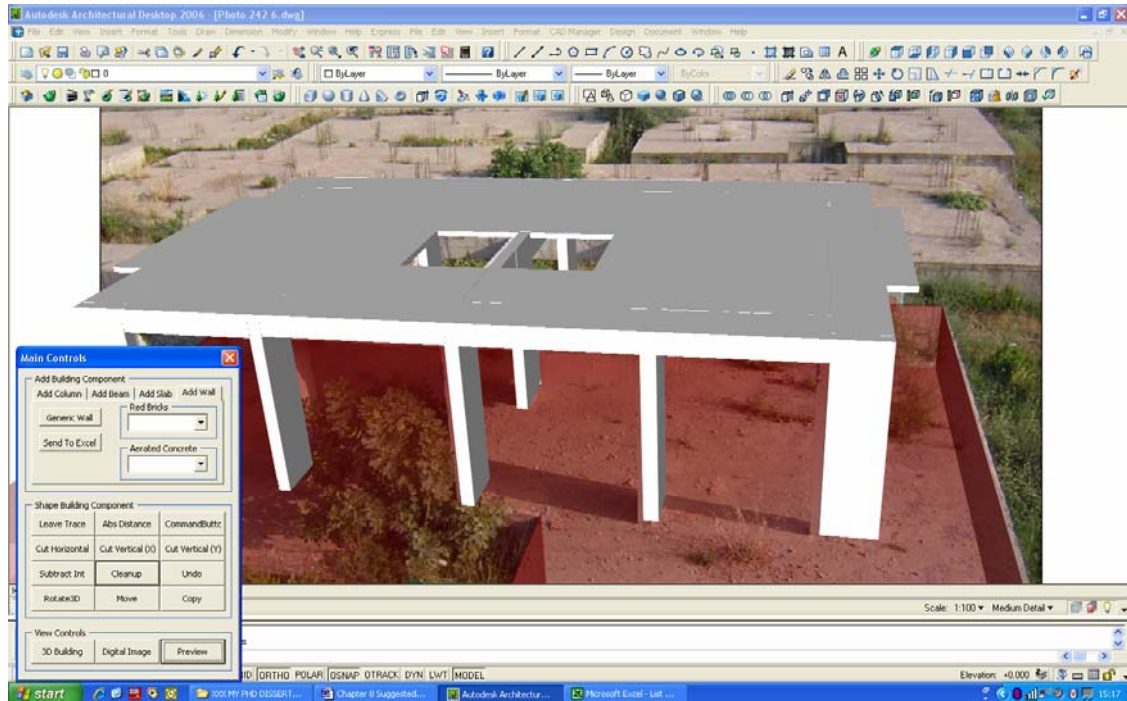


Figure 8.7: An example of the 3D model is “preview” view setting

The “preview” view setting is only for viewing the progress and checking the quality of the measurements visually. In this setting, operator is not allowed to keep modelling due to the limitations of AutoCAD perspective projection view settings. In order to continue modelling, the operator should first switch to the 3D model view, or for measurement purposes; s/he should switch to the “Digital Image” view setting.

8.8. Component Editor or “Shape Building Component” Functions

The component editor functions are located at the middle section of the “Main Controls” control box. Under this section there are measurement and 3D editing related tools. When a component’s size needs to be measured using photogrammetry or whenever a 3D building element needs to be re-shaped, copied or erased these controls

are used. These functions, and how they are used and created, are explained under the following sections.

8.8.1. Leave Trace

This is the main technique of taking measurements from the digital image. This command automatically sets the view and UCS settings to “Digital Image” settings so that the user can specify a pair of points on the image to leave a trace of the line on the image to the 3D model (figure 8.8).

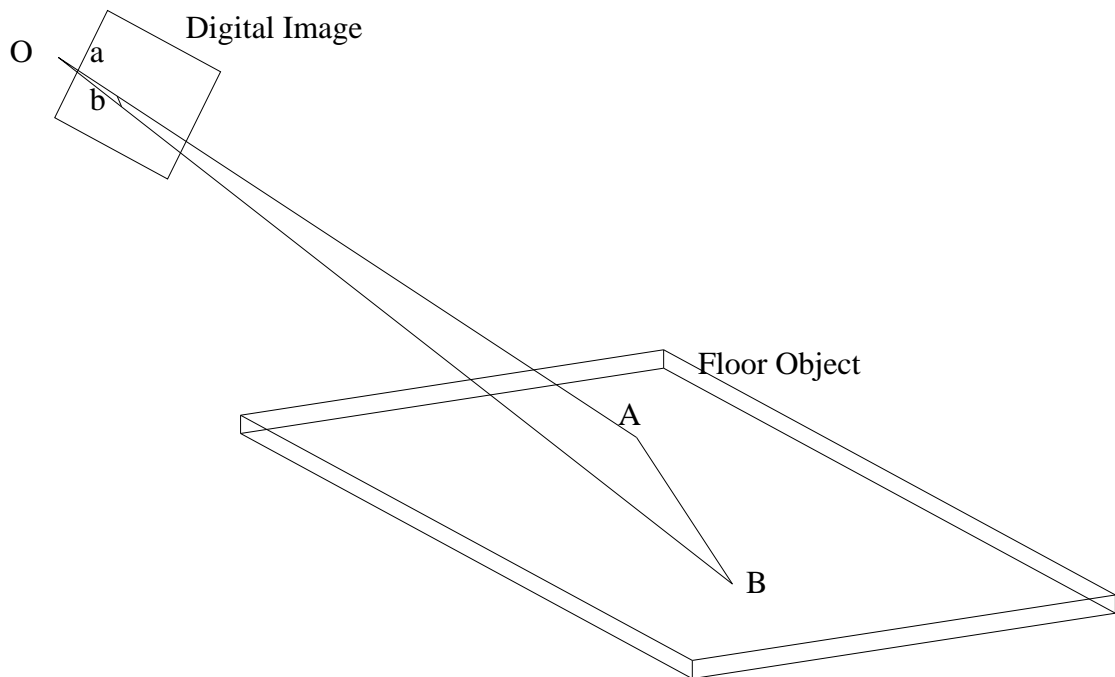


Figure 8.8: Co-linearity principle is applied by the “Leave Trace” function. When image points “a” and “b” are clicked, they are projected to the floor object as “A” and “B”, while “O” is the lens centre.

This function uses the co-linearity rule of computer vision and photogrammetry to leave traces on the 3D model. Because the lens centre, the image point and the scene point are all co-linear, the code creates a region object on the selected 3D object by using 3 points

(2 points given by the user and the lens centre is the default as the third point). For example if a column object needs to be located on a floor object, lower edges of the column on the image must be clicked so that a pair of traces can be left on the floor. The intersection of the traces gives the location of the corner of the column edges whilst traces themselves give the horizontal directions of the column. All these traces are regular AutoCAD “region” objects, and when the modelling sequence is complete, they are erased by the “clean up” command.

8.8.2. Abs Distance

This is similar to “dist” command of AutoCAD. When the code is active, AutoCAD menus are inaccessible; therefore a 3D measurement command is needed to measure the product as the code is in “run time”. If the user needs to measure an item on the 3D model (not the image) this command is used. After a pair of points is specified from the 3D model an AutoCAD pop-up emerges and lists the absolute distance, DX, DY and DZ distances between the two points (see figure 8.9). This pop-up window is a VBA text box. When the user clicks “Ok” the main controls application becomes visible again.

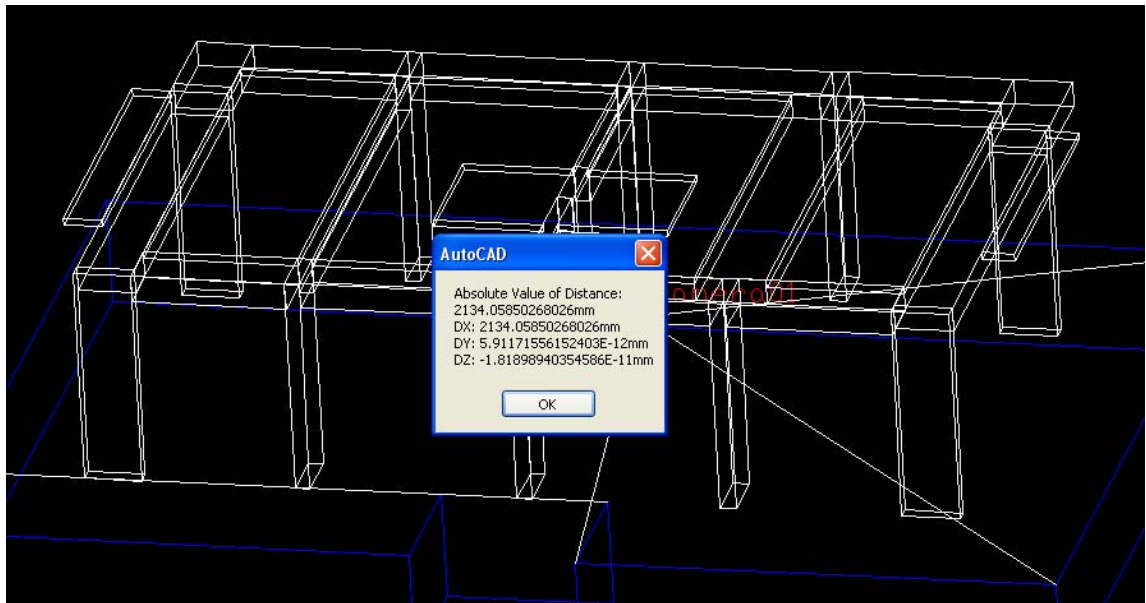


Figure 8.9: The result of Abs Distance command after two points selected

This command can be useful when a building component has the same size as another one as the previous size can be measured and can be specified for the next component.

8.8.3. Cut Horizontal

Standard building elements within the model are all specified with their uniform dimensions. This means a column in a dropdown menu would be named and created after its horizontal dimensions. A column with 250x500 mm size needs its height specified by either using the height of the previously created column or by a photogrammetric measurement. In the second case this means the excessive height of building elements have to be cut horizontally.

The “Cut horizontal” command works similar to AutoCAD’s “slice” command. However, since it only cuts horizontally, it needs only one point to be specified on the cutting plane. A plane in 3D space can be defined by 3 points, so the other two points needed are given by the code itself to create a horizontal plane. Using the point given by the user and other two points created automatically by the code, the “slice” method is

initiated and the selected 3D object is horizontally cut. As the result of the cutting operation, the original solid is destroyed and two new solids are created. The user can use the “clean up” procedure to erase the undesired half of the object.

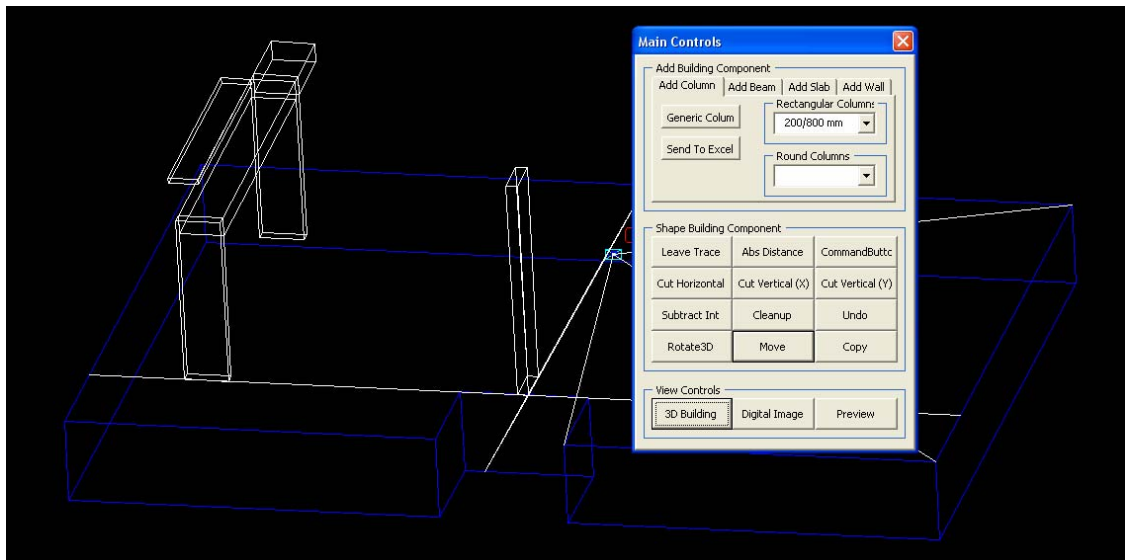


Figure 8.10: An example of a 200/800mm column which is too long and requires a horizontal cut.

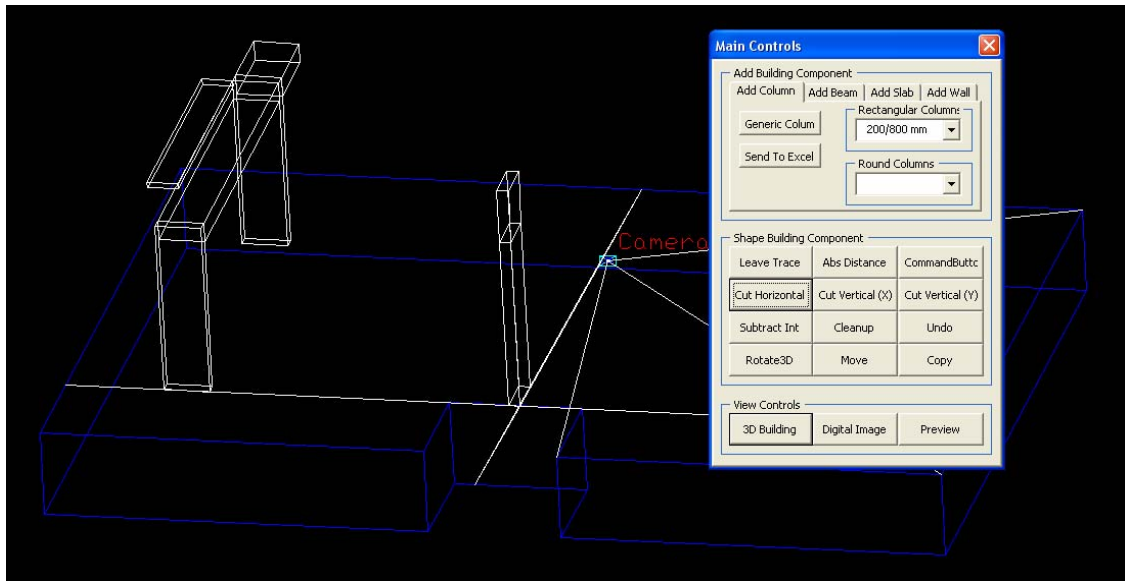


Figure 8.11: After the “cut horizontal” command, the column is cut from the height of the next column. Only one point from the top of the next column is specified.

Figure 8.10 and figure 8.11 show an example of “cut horizontal” command in the application. In these pictures the 200x800mm column in the middle is inserted from a dropdown menu, but the height of it is too tall. It needs to be cut to the size of the previous column, so the user clicks the top of the first column on the left once to specify the horizontal slicing plane. This operation cuts the new column to the same size as the first one.

The AutoCAD VBA application uses the world coordinate system (WCS) for 3D operations, therefore the code was written to convert the 3D building UCS coordinates to the WCS and back to the initial UCS automatically without interrupting the operators modelling procedures.

8.8.4. Cut Vertical (X)

The cut vertical operation is similar to the horizontal cutting operation with one difference. This time the code creates a vertical plane to cut the desired object from the point clicked by the user.

In horizontal plane, the cutting operation happens perpendicularly to the Z axis. In vertical direction there are two possibilities. The “Cut Vertical (X)” command cuts the object parallel to the X axis. Both parts of the original 3D object are retained after the cutting so that the operator can use the “Clean up” procedure to erase unwanted part.

8.8.5. Cut Vertical (Y)

The second possibility of cutting in the vertical direction is the “Cut Vertical (Y)” command which cuts the objects parallel to the Y axis. The user specifies the point to create a plane, vertical and parallel to the Y axis, and the code creates the cutting plane and cuts the object. Both parts of the original solid are retained after the cutting so that the operator can use the “Clean up” procedure to erase unwanted part.

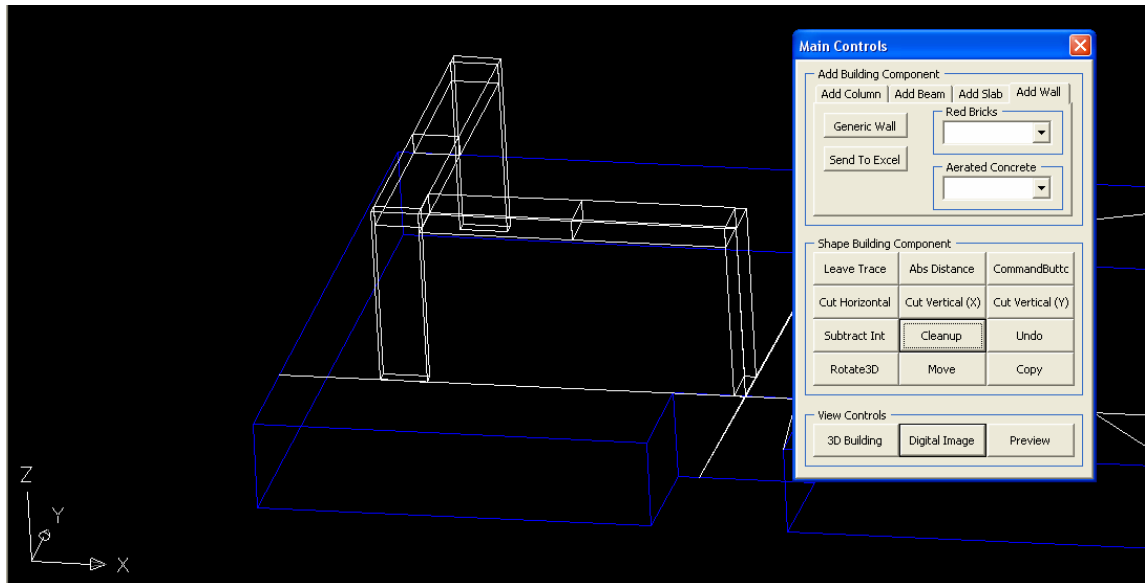


Figure 8.12: The beam in the X direction was cut vertically and parallel to the Y axis while the beam parallel to the Y axis is cut vertically and parallel to the X axis

Figure 8.12 shows two beams cut, respectively parallel to the X axis and parallel to the Y axis, using “Cut vertical (X)” and “Cut vertical (Y)” procedures of the code. Both beams were cut in the middle creating one pair of new objects each, destroying the original solids.

8.8.6. Subtract Interference

Occasionally, after adding 3D objects to the CAD space, some parts of the building components overlap. This causes interference between the components and reduces the accuracy of the volumetric calculations, e.g. interfering parts of the solids would be measured twice unnecessarily (figure 8.13).

The subtract interference procedure sculpts out these overlapping parts using the “subtract” command of AutoCAD VBA. The 3D coordinates are translated between the UCS and WCS automatically as required.

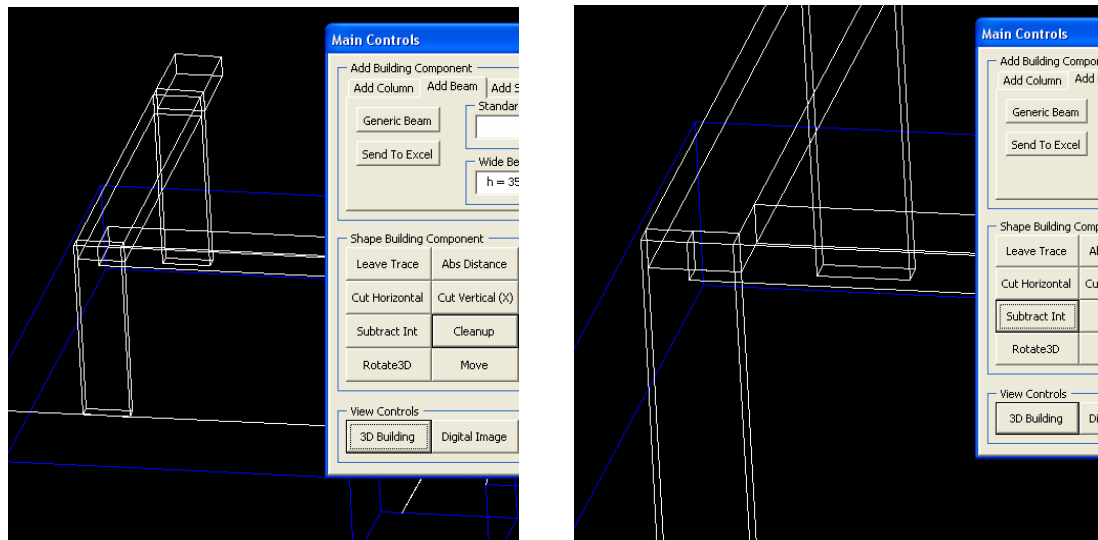


Figure 8.13: There is an overlapping corner of the beam in the first image, and the second image shows the CAD model after the subtraction (there is still some interference left due to the corner of the column)

8.8.7. Clean Up

This command deletes the selected objects. It works very similar to the standard “erase” command of the AutoCAD. Traces left for measurement purposes, or surplus parts of the cut objects are all erased by the “clean up” procedure permanently unless an undo command is initiated.

8.8.8. Undo

This is a standard undo command. A number is entered to specify the number of operations to undo. When the code is in run time, AutoCAD’s standard “undo” command becomes inaccessible. In such cases the built in “undo” command on the main controls becomes necessary and useful.

8.8.9. Rotate 3D

The 3D building components are inserted to the drawing space by specifying their sizes relative to X, Y and Z coordinates. Therefore generally they would be created correctly oriented to their space without any additional orientation required. However, the elements are occasionally required to be at a different orientation than being parallel to the coordinate systems. In such cases they can be rotated around a specified vector by specifying a rotation angle. This command can help if the operator makes a mistake during the 3D component insertion process. Any component inserted in a wrong orientation can be re-oriented by the “Rotate 3D” procedure. This command is a simplified version of AutoCAD’s “Rotate 3D” command. It is useful because the original “Rotate 3D” command is inaccessible during the run time of the code. When the rotation axis is defined, the code transforms the user input coordinates between WCS to the UCS automatically.

8.8.10. Move

This command moves the objects along a vectors positive direction. The vector is defined by clicking two points. The first point is the start point and the second is the end point of the displacement. Necessary coordinate transformations between WCS to UCS are done automatically. Points can be entered from the keyboard as 3D coordinates or by clicking on the screen with a mouse. The object itself is not modified by any other means than its 3D location.

8.8.11. Copy

The AutoCAD VBA copy method is different than the “copy” command of AutoCAD. In the VBA version of the copy, the copied objects do not move to a different location. They emerge exactly at the same location, interfering with the original object. Therefore the procedure of the code first copies the objects and starts a “move” procedure which creates the displacement. The end result is very similar to the original AutoCAD “copy” command however, the original “copy” command of the AutoCAD is inaccessible

during the run time of the code, and therefore it is needed as a separate command. The user selects the object to copy, specifies the base point and the second point of the displacement, so that the code drops the objects to the new location. Necessary coordinate transformations between WCS to UCS are done automatically.

8.9. Add Building Component Functions

The “Add Building Component” functions are the actual modelling tools of the proposed system. They are located at the top of the “Main Controls” control box. This tool group consists of four sub-divisions separated from each others by various tabs. These tabs are “Add Column”, “Add Beam”, “Add Slab”, and “Add Wall”. Each tab contains the tools necessary to create the relevant building components. They are similar with each other in layout to maintain consistency and convenience. Each of these tabs is explained in the following section.

8.9.1. “Add Column” Tab

This tab offers two basic ways of creating a column in the specified location. The newly created column would be upright oriented to the UCS of the floor object that the column is located on.

The first way of creating a column is using the “Generic Column” button, located on the upper left corner of the tab area. This tool creates a rectangular and free shaped column with no size limits in any direction. It is suitable for the earlier stages of the modelling process when the operator doesn’t have any idea about the approximate dimensions of the columns.

When the “Generic Column” command is initiated, the user is asked to specify the location (a 3D point), the depth (X direction size), the width (Y direction size) and the height (Z direction size) of the column to be created. Location and sizes can be inputted from the keyboard as numbers or can be clicked on the screen by the mouse. Negative

entries are accepted for the negative directions of the coordinate system. The user can enter these dimensions randomly, trying to stay larger than needed in the estimates. After creating the column larger than necessary, the user can now initiate as many as needed “Leave Trace” command sequences to find out the actual limits of the column. The “preview” button can be used to see in which directions the column needs to be sculpted. Finally by using “cut horizontally”, “cut vertically” commands, the column can be brought down to its actual size. Once this simple operation is complete, the length of all the columns used on this floor will be known in addition to the general sizes of the other columns. This information can then be used in further simplification in the creation of the rest of the columns.

The alternative method to the “Generic Column” in column creation is using the dropdown lists and selecting the column size from there. There are two dropdown lists: one for the standard rectangular columns and one for the standard round columns. Both of the dropdown lists are populated using the construction knowledge as explained in chapter 7. The most common column types for this construction type, and the building size shows similarities (see Chapter 7). Therefore the users can find the type of columns they need easily from the dropdown lists. In fact, since the first column might have been created with “Generic Column” procedure, some of the dimensions of the column to be chosen from the list would already be known (see figure 8.14).

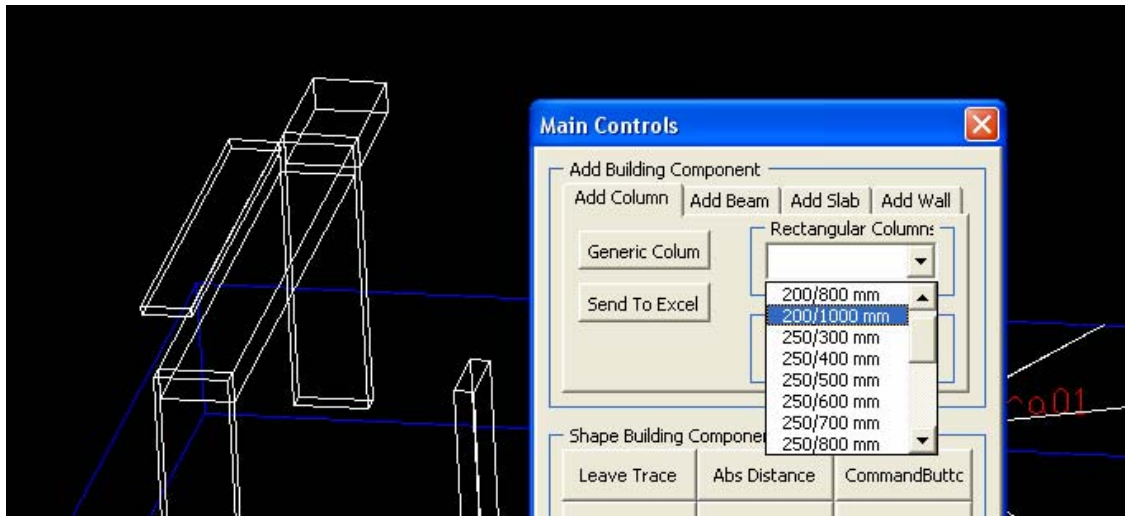


Figure 8.14: User can access the “Rectangular Column” dropdown list and select the necessary size.

Combinations of the “Generic Column” function and the dropdown lists of the standard columns offer the user the opportunity to create columns from any size with considerable flexibility and speed.

8.9.2. “Add Beam” Tab

Similar to the “Add Column” tab, the “Add beam” tab also offers various ways to create 3D models of the different beam types. Operator’s methods to follow also resemble the “Add Column” procedures.

The first method to create beams is the “Generic Beam” procedure. This procedure creates a free size beam in any direction. The operator is first asked to specify the start point and, the X direction length of the beam. The X direction length can be the actual width or length of the beam depending on the orientation of the beam relative to the UCS. As a second step of the procedure, the user specifies the height (vertical thickness) of the beam. This can be given as a positive or negative number or a pair of 3D points to specify a distance. This distance can be specified from a previously created beam or any distance that looks larger than what is needed. Finally the Y direction length is inputted.

Both X and Y direction sizes can be inputted as a number from the keyboard or as a 3D point from the screen using the mouse. From the “Preview” view control button, the user can see the result of the modelling operation. If there are inaccuracies, the “Leave Trace” procedure can be used to figure out the correct size of the model, and the object can be “Cut Vertically” or “Cut Horizontally” to be reduced to the actual size.

An alternative option to the “Generic Beam” procedure is to use either one of the two dropdown lists, depending on the type of floor used in the building design. If the building has a hollow-tile floor type design, the “Wide Beams” dropdown list would be suitable. There are five alternative beam thicknesses depending on the type of hollow-tile used. The operator can recognise the type used for the project by the trial method or by using the “Leave Trace” method. An experienced operator would spot the type of the hollow-tiles instantly by looking at the images since, out of the five alternative hollow-tiles available, only three are actually commonly used in Turkish construction industry.

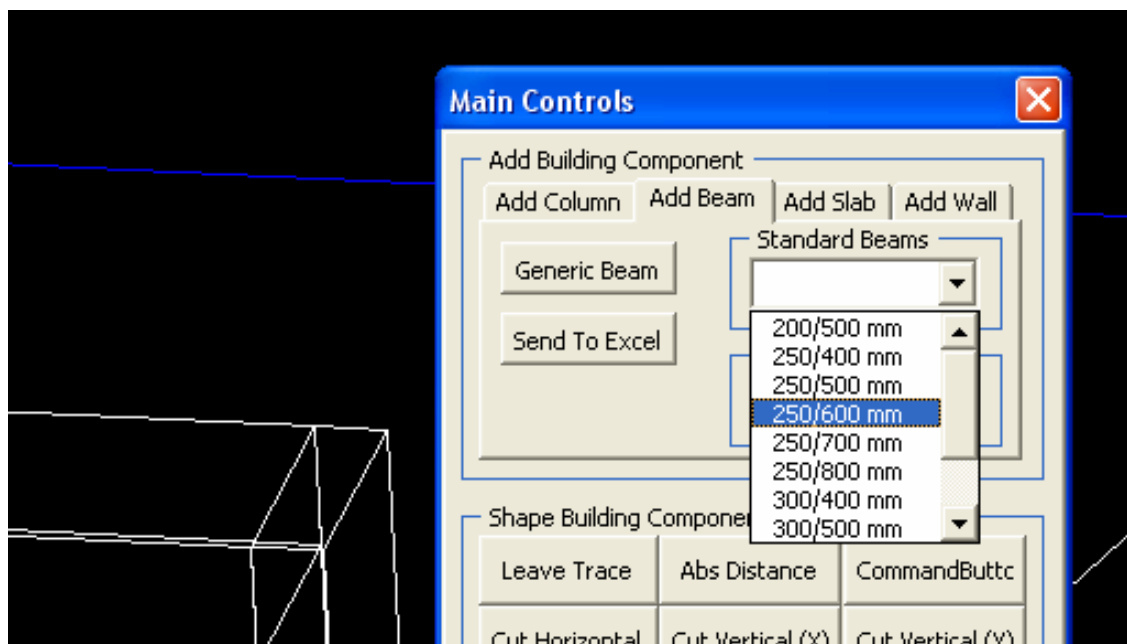


Figure 8.15: “Standard Beams” dropdown list

The other alternative beam type is available in the second dropdown list (figure 8.15). This list is made of the most common beam types used in summerhouses within Turkey. The buildings are used for the same function and are very similar sizes. They are all made of the same materials. Therefore the structural dimensions show many similarities as explained within chapter 7. The dropdown list of the “Standard Beams” reflects these similarities that stem from the functional requirements like the wall thickness or the industry norms and regulations.

8.9.3. “Add Slab” Tab

This is where the 3D slab creation tools are located. Like the “Add Column” and the “Add Beam” tabs, the “Add Slab” tab is also laid out in a similar way, offering two main types of methods for slab creation.

The horizontal external dimensions of the slabs are relatively easy to find out. In many cases a slab is surrounded by the beams. Therefore the critical dimension to seek for a floor slab is the vertical thickness. Fortunately there aren’t many alternative floor thicknesses used within the Turkish construction industry. There are two dropdown lists containing those common floor thicknesses (Figure 8.16).

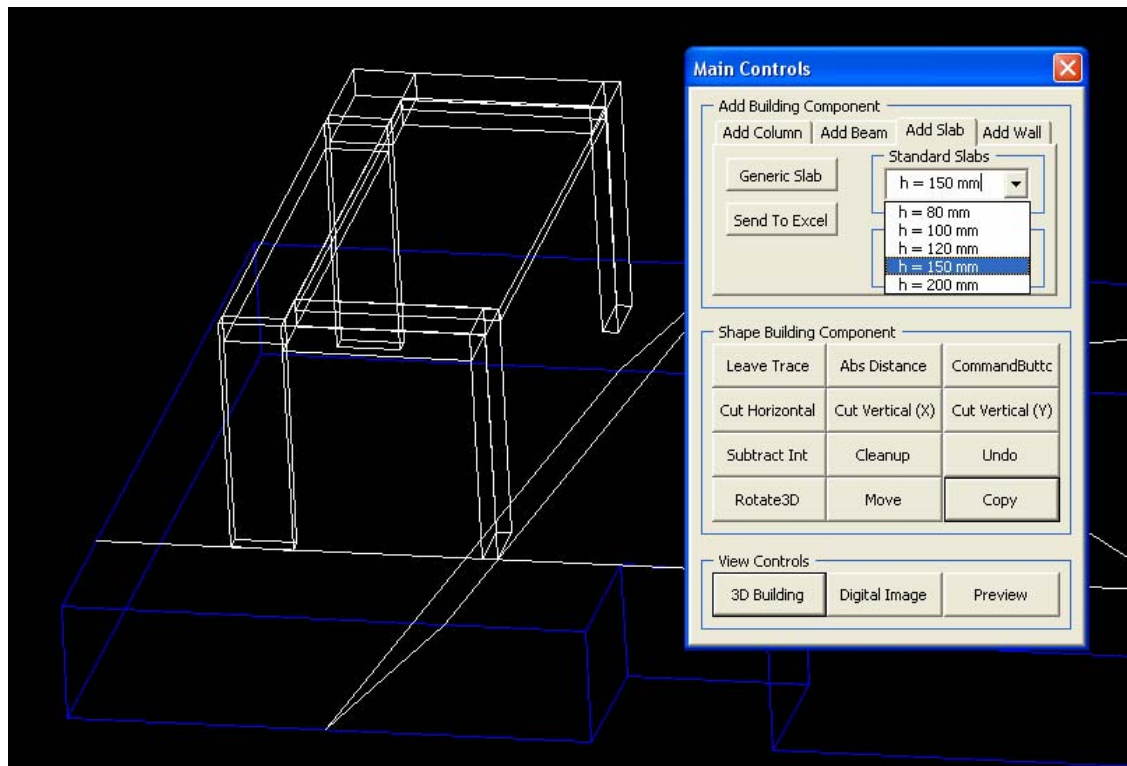


Figure 8.16: Standard slabs dropdown list

In both dropdown lists the user can select the type of thickness used on the construction and specify a rectangle representing the plan shape of the floor. This is generally done by clicking two diagonal opposite corners of the beams surrounding the slab.

The “Generic Slab” button can also be used to create a slab with an unknown thickness. In this method the user is asked to specify the plan of the floor in a rectangular shape. Two diagonal points are entered as start and end points, and finally the thickness of the floor is entered. If none of these dimensions are known or are limited by the beams, the operator still can use the “Leave Trace” function and, by “Cut Horizontal” or “Cut Vertical” procedures, the generic floor can be shaped as needed.

8.9.4. “Add Wall” Tab

There are two ways of creating a wall. The user can create the wall from scratch by the “Generic Wall” procedure or chose the type of wall necessary from one of the two dropdown lists.

The “Generic Wall” procedure asks user to specify the start point of the wall first. A 3D point can be entered from the keyboard or a point can be clicked by the mouse. This point is generally a lower corner of an adjacent column since this is where the masonry work begins. The second input code required is the X direction length of the wall. A number in millimetres can be entered as the length of the wall in X direction or a second point can be clicked by the mouse. In practice, this second point would generally be the opposite column’s lower corner. After this, the height of the wall is specified by a pair of point entry. Finally the Y direction length of the wall is entered. The “Generic Wall” is a very rarely used procedure since there are very few standard blocks in the Turkish construction industry. Therefore the user would generally opt to use one of the two dropdown lists instead of the “Generic Wall” procedure.

The first of the dropdown lists is the “Red Brick” option. In this list the user is offered to choose from one of the three red brick thicknesses available in the market. The great majority of the reinforced concrete frame structures use all three red brick wall types together. As explained in chapter 6, there are actually two bricks that offer three different wall thicknesses. These bricks are 195x195x135mm and 195x195x85mm thick. The 195x195x135mm ones can be laid upright to create 135mm wall thickness or horizontally to create 195mm wall thickness. These configurations are used for the outer boundaries of houses depending on the level of thermal insulation needs. The 195x195x85mm ones are only laid upright and give a wall thickness of 85mm. This is suitable as a separator between different rooms in the same house. This level of information is enough to select the right type of wall thickness from the list. Any operator with a minimum level experience can recognise the type of wall thickness used on the construction from an image.

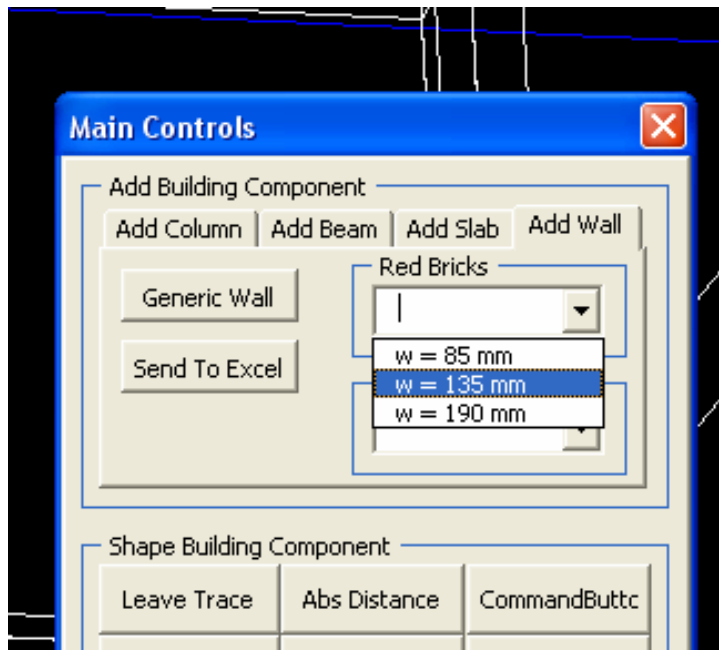


Figure 8.17: The “Red Bricks” dropdown list

The second type of walls is Autoclaved Aerated Concrete (AAC), therefore the dropdown list is named “Aerated Concrete”. This type of wall is not generally used on summerhouses, since they are known as thermal insulation wall materials and are more expensive. The alternative sizes on the AAC can be selected from the second dropdown list.

8.10. “Send to Excel” Buttons

The Excel application automatically starts working in the background as soon as the “main controls.dvb” application is loaded and executed. It is in the system tray as a minimised program.

The “Send to Excel” buttons are located at the same place for every tab within the “Add Building Component” functions zone. Each time the operator is satisfied with the result of a modelling process, finished building components can be exported to the Excel spreadsheet for financial reporting purposes. During the exportation process, the user is

asked to provide the name of the building component. The code calculates the volume of the component and writes this information to the cells of the Excel file previously created.

The exportation process is slightly different between the concrete elements and the brick walls, but is essentially very similar. Bricks are priced the same way no matter how wide or narrow the wall is, since the price is for the total volume. Concrete is also priced by the volume but, the price also depends on the type of concrete being cast.

The Excel spreadsheet has the typical configuration of a bill of quantities (see figure 8.20). The Excel spreadsheet on the figure 8.20 is the result of the 3D modelling activities on figure 8.18. It is automatically created by the code from the data available on the digital image (figure 8.19). As the items on the CAD space are exported to Excel spreadsheet, they are automatically being sent to the layers created by the code, in order to deal with the complexity of the 3D mode. Since different materials appear within the different layers, and therefore different colours, the user is unlikely to export the same item twice.

Chapter 8

Proposed Method Explained Using a Case Study

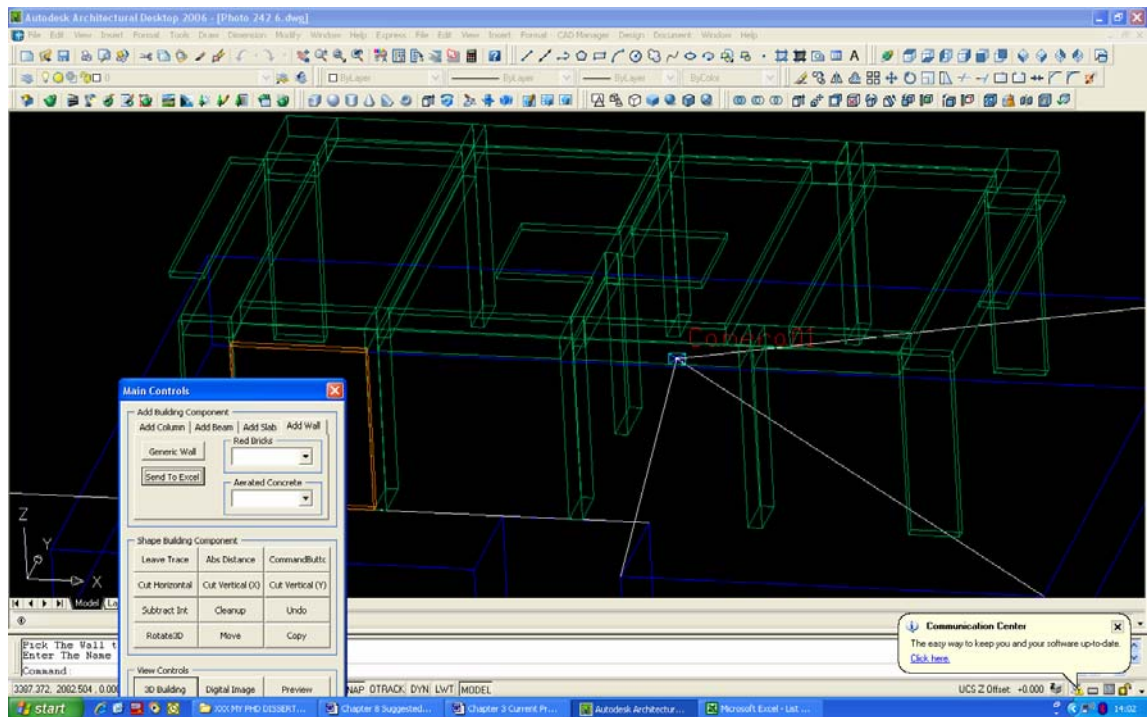


Figure 8.18: The 3D model in this image is the product of the information extracted from figure 8.18

The 3D model on figure 8.18 can be created and measurements can be exported to the Excel sheet in a time period of 30 minutes within the convenience of the office space after the initiation of the code. Considering the difficulties explained within chapter 4, the method can be considered as a major development. It can offer additional comfort in progress measurement and reporting for the project team members.

Chapter 8

Proposed Method Explained Using a Case Study

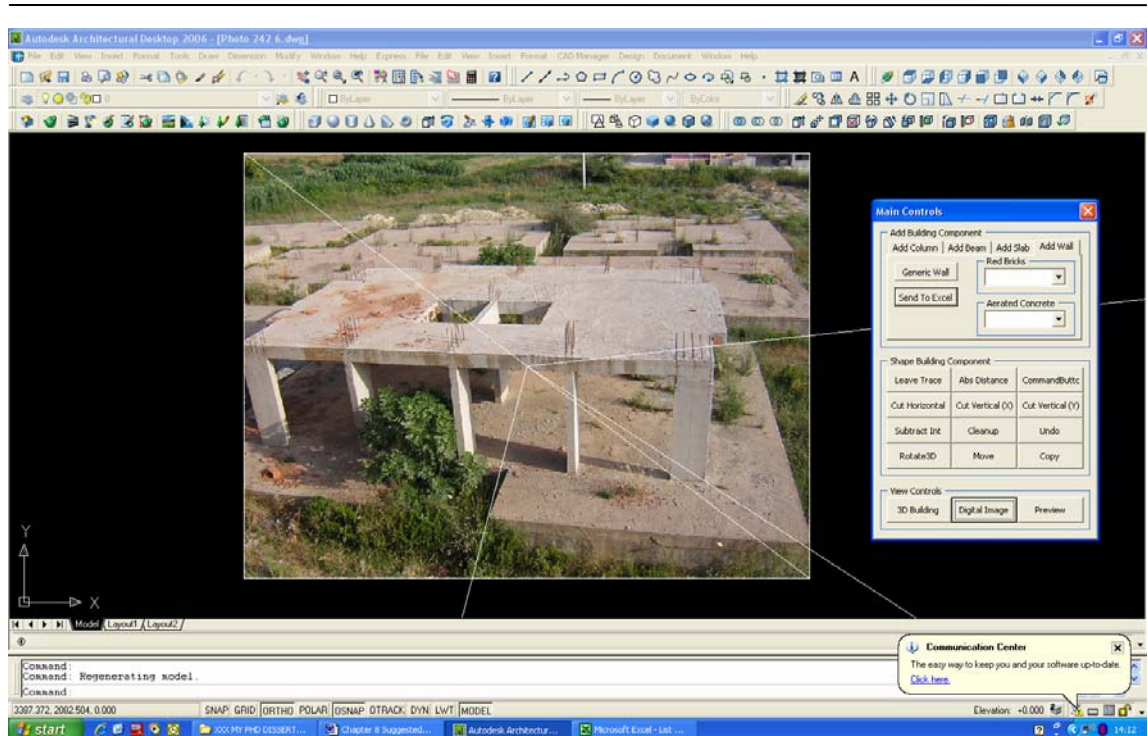


Figure 8.19: This is the image which was imported to AutoCAD, in order to be used for 3D modelling applications

The prices on the Excel sheet are currently derived from the code. However, they can also be linked to another Excel sheet that can be an attachment of the current contract of the project. The source file can also be on a network or it can be retrieved from the web with a small modification to the code (Sutphin 2004).

Chapter 8

Proposed Method Explained Using a Case Study

Project Name: Kusadasi S.House						
Date: 12.06.2008						
Item	Material	Unit	Unit Price	Quantity	Cost	
1	Column G1	C20	m3	10	0.530	5.303
2	Column G2	C20	m3	10	0.530	5.303
3	Column G3	C20	m3	10	0.494	4.939
4	Column G4	C20	m3	10	0.494	4.939
5	Column G5	C20	m3	10	0.513	5.131
6	Column G6	C20	m3	10	0.608	6.083
7	Column G7	C20	m3	10	0.513	5.131
8	Column G8	C20	m3	10	0.559	5.593
9	Column G9	C20	m3	10	0.559	5.593
10	Column G10	C20	m3	10	0.490	4.899
11	Column G11	C20	m3	10	0.490	4.899
12	Beam F1	C20	m3	10	1.615	16.154
13	Beam F2	C20	m3	10	0.603	6.034
14	Beam F3	C20	m3	10	0.238	2.377
15	Beam F4	C20	m3	10	0.266	2.657
16	Beam F5	C20	m3	10	2.112	21.118
17	Beam F6	C20	m3	10	1.648	16.481
18	Beam F7	C20	m3	10	0.672	6.724
19	Beam F8	C20	m3	10	0.606	6.065
20	Beam F9	C20	m3	10	0.386	3.856
21	Beam F10	C20	m3	10	0.816	8.156
22	Beam F11	C20	m3	10	0.816	8.156
23	Beam F12	C20	m3	10	0.740	7.397
24	Beam F13	C20	m3	10	0.741	7.406
25	Beam F14	C20	m3	10	0.651	6.511
26	Beam F15	C20	m3	10	0.651	6.511
27	Beam F16	C20	m3	10	0.398	3.977
28	Slab F1	C20	m3	10	0.228	2.284
29	Slab F2	C20	m3	10	1.288	12.876
30	Slab F3	C20	m3	10	1.468	14.579
31	Slab F4	C20	m3	10	1.063	10.634
32	Slab F5	C20	m3	10	1.149	11.489
33	Slab F6	C20	m3	10	0.182	1.820
34	Wall G1	8,5/13,5 or 19 cm Red Blocks	m3	5	0.764	7.644
35			m3			
36			m3			
37			m3			
38			m3			
39			m3			
40			m3			
41			m3			
42			m3			
43			m3			
44			m3			
45			m3			
46			m3			
47			m3			
48			m3			
49			m3			
50			m3			
Page Total:					248.716	

Figure 8.20: The total number at the bottom of the sheet is BCWP for the date of the snapshot

8.11. Conclusions

This chapter explained step by step how the prototype code created in this research works. The chapter emphasised why the code was useful and how it makes the calculations of BCWP easier. Custom made functions of the code were introduced and examples of their use were given. A digital image was used to create the 3D model of the construction initially, and the elements of this 3D model were used to create an Excel spreadsheet in order to create the BCWP. BCWP is the much needed information for project team members, to allow them to monitor cost and schedule variances. The code has proven to be very useful in creation of BCWP and is expected to be very helpful at reducing conflicts and communication problems within the project teams with its visual aiding ability. The 3D model created was accurate and was easy to produce. Use of the application proposed is much faster than conventional measurement methods such as going to the construction site and literally measuring the work. The end product is very easy to understand by anyone and the interim or final payments can be justified easily by the contractors.

Chapter 9: Evaluation	170
9.1. <i>Introduction</i>	170
9.2. <i>Outcomes Versus Targets</i>	170
9.2.1. Evaluation of the 3D Models Created	172
9.2.2. Evaluation of the Volumetric Calculations	173
9.2.3. Evaluation of the Spreadsheets	174
9.2.4. Data Format Conflicts, Data Re-entry and Data Losses Avoidance	176
9.3. <i>Reactions and Comments from the Industry</i>	178
9.3.1. Positive Reactions	178
9.3.2. Negative Reactions	179
9.4. <i>Conclusions</i>	179

Chapter 9: Evaluation

9.1. Introduction

This chapter aims to evaluate the accuracy, validity and usefulness of the model proposed in this research. Evaluation is a critical part of academic research since it is not easy to find a totally unambiguous measurement strategy for the evaluation of an academic research. For a qualitative research project there might be various different evaluation tactics applicable, however, in a quantitative research such as this one, comparison of numerical data is the main source of evaluation. Therefore, in this research, construction work was initially measured manually on site in order to obtain as-built data. This data was then compared with the measurement results obtained from the proposed model in order to determine the precision of the model.

Whilst quantitative data can be evaluated by numerical comparisons, the qualitative properties of the proposed model, such as usefulness or practicality are not easy to measure. Consequently, in order to resolve these problem, informal interviews were conducted with the representatives of the Turkish construction industry, from both client and contractors sides.

9.2. Outcomes Versus Targets

In order to make a comparison between the outcomes of the research and the initial targets, a summary of the aims and objectives must be made. The introduction (chapter 1) and main motives (chapter 4) chapters describe the aims and objectives of this research in detail. A summary of these objectives is described in the current section.

It was declared at the beginning of this thesis that although an automation based solution to reduce the cost and schedule variances of the construction projects could be useful; it could also create data exchange problems. Therefore, a method that can produce data which is usable by other applications, easily understandable by clients from other industries and can control the cost and schedule variances is needed. The aim

of this research was to create a prototype computer application to resolve such problems. The data produced by the proposed application must be exportable or exchangeable by other computer applications such as Virtual Reality or types of planning and scheduling software applications.

Since the industry suffers from a lack of as-built data, the application created must provide the budgeted costs of the works performed (BCWP) easily and accurately so that the project managers can control, monitor or alter their schedules on time, without suffering large cost or schedule overruns. If the BCWP delivered accurately and promptly from the construction site, more conventional progress measurement methods such as Bar Charts, Network Diagrams, Earned Value Analysis, S curves or Line of Balance Diagrams can be supplied with the information required to be more useful. Project Managers can benefit from the full potential of these methods. Therefore, this research aimed to create a prototype computer application which calculates BCWP. The performance of this application will be evaluated in this chapter.

In this research, it has been reported that the clients of the construction industry are not always experienced in the building procurement, or they are often unable to completely understand the construction documentation, hence the output of the proposed model had to be easy to understand. Results had to be unambiguous and uncontroversial to avoid conflicts that are common within construction project teams. Therefore, the application aimed to provide sufficient visual aid to the customer via 3D CAD models.

A prototype software application was created and introduced in Chapter 8. This application has been tested on a summer house construction. Images of the construction have been captured in Kusadasi, Turkey. The building was also measured manually in order to make meaningful comparison with the proposed model. The results of the manual measurements can be found in Appendix 2 of this thesis as 2D plans and sections.

For the proposed method, the aims were to measure construction progress, prepare the documentation for payments and support the documentation with convincing visual

materials. All these objectives and the performance of the model versus these targets are explained in the following sections.

9.2.1. Evaluation of the 3D Models Created

Initial camera alignment between the 3D CAD objects and the image was achieved by the VizRender software application. The software overlaps the image and 3D CAD objects with a reasonable approximation and the measurement results are suitable for construction progress monitoring purposes. Accuracy can be improved if a calibrated camera is used with professional photogrammetry software such as PhotoModeler Pro instead of an approximate camera alignment achieved by VizRender. Actual focal length of a camera can only be found by a calibration process achieved by a tool like PhotoModeler Camera Calibration Tool. For this research, the focal length value was taken from the user manual of the camera manufacturer.

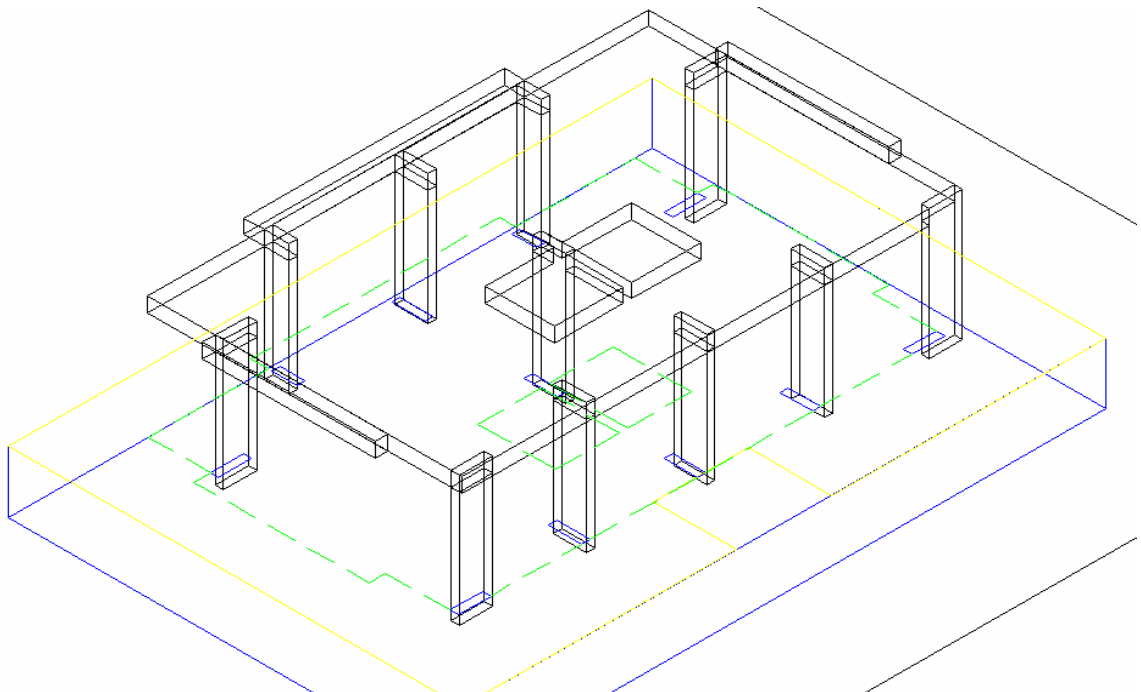


Figure 9.1: 2D as-built drawing projected over the 3D model created by the application. Notice that the columns do not overlap perfectly

The 3D building model in figure 9.1 was created as a result of measurement activity undertaken using the proposed model. An as-built ground floor plan drawing was also projected to the floor of the 3D model in order to reveal imperfections of the locations of the columns found by the proposed model. Blue rectangles represent the correct locations of the columns. Due to inaccuracies made by VizRender about the camera and 3D model orientation, the 3D model created by the proposed application shifted uniformly in positive Y axis direction within the region of 15 to 25 centimetres. This shift did not affect the sizes of building components created. The distances between the columns were uniform with much smaller mistake margins of 2 to 5 centimetres. Building components themselves were perfectly dimensioned with no visible mistake margins in either X or Y directions due to the effect of the building standards and knowledge reflected to the model. The Z direction mistake margin (in heights of the columns) was in the region of 0 to 4 centimetres. All of these smaller inaccuracies can be attributed to manual point selection process. The user specifies the lines and corners on the picture by manually clicking on them with the pointing device of the PC. Therefore, this part of the process can be seen as a form of manual measurement activity. Hence, they contain similar inaccuracies with manual measurements taken on site.

Since the distances between the columns are preserved, the beam lengths are also accurate. Therefore, the sizes of the building components are correct with regard to suitable accuracy margins. The 3D model created using the proposed application was found to be useful for progress measurement purposes. It correctly represented the building under construction and therefore the clients were able to rely on the calculations extracted from them. Mistake margins were the same or often much smaller than what could be achieved by manual surveying methods considering the fact that the objects to be measured were very large for human scale on site.

9.2.2. Evaluation of the Volumetric Calculations

The accuracy of the volumetric calculations is excellent once the 3D model has been correctly produced due to its automatic nature. After a 3D model of a building

component has been created, the volume of the material used in the body of the element was automatically calculated as the user selected the data and transferred it to an Excel spreadsheet. The precision of these volumetric calculations are finer than millimetres in level. The accuracy of the automatic volumetric calculations were found to be well beyond the requirement of the construction progress measurement purposes since concrete on site is cast in cubic meters (m^3) and the walls are also priced in cubic meters (m^3) in Turkish construction industry. As a result it can be concluded that the calculations in cubic millimetres are perfectly precise.

Any mistake that may happen in volumetric calculations is likely to come from 3D model creation, since it is the only part with human manual intervention. Once the 3D model is created, the rest of the calculations and data transfers occur automatically. Therefore these calculations do not contain error margins.

9.2.3. Evaluation of the Spreadsheets

Visual Basic for Applications (VBA) code automatically calculates the quantity of the building component selected from the 3D model, and exports it to an Excel sheet cell. This quantity is also automatically multiplied by the unit price of the material specified by the code. The type of the material is semi-automatically specified depending on the type of building component. This means if a column is being exported to Excel, the user only has to manually specify the type of the concrete. This is because the model can not know if the structural project drawings had specified the column material as C20, C30 or any other concrete type, therefore the user is asked to manually select from a sub selection set of suitable materials. The choices available are very few but the selection is still done by the user, therefore, in order to maintain the accuracy of the financial calculations, the user must enter the correct material name, so that the correct unit price can be multiplied with the quantity. The same issue exists at a more complicated level with the traditional methods to create the bills of quantities since the materials are selected and manually entered from an indefinite set of materials instead of a small set of possible materials to choose from. Therefore, the proposed method is by far the safer option.

The process in which the building components are exported to the Excel sheets are explained in figure 9.2.a, b, c, d.

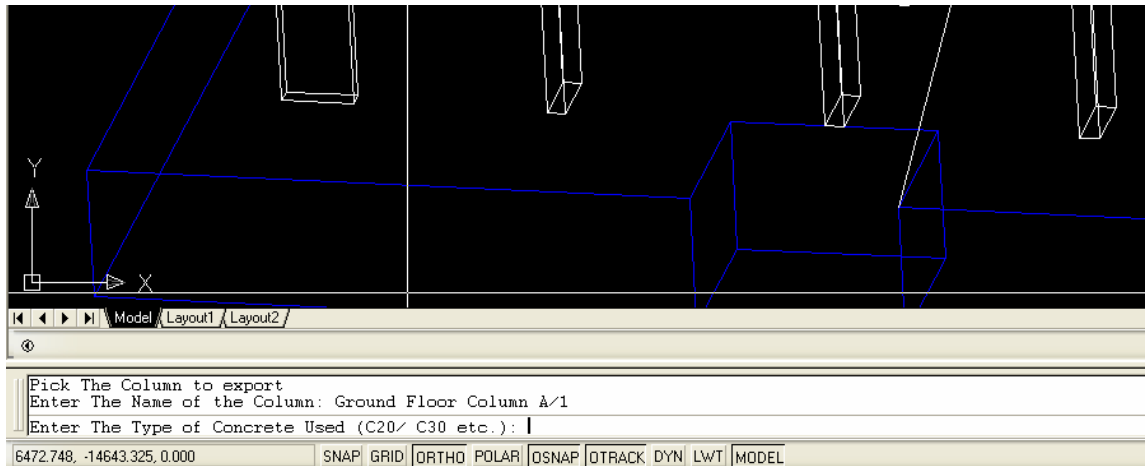


Figure 9.2.a. The operator is being asked to pick the column to export, name it and specify the material by choosing from C20 or C30.

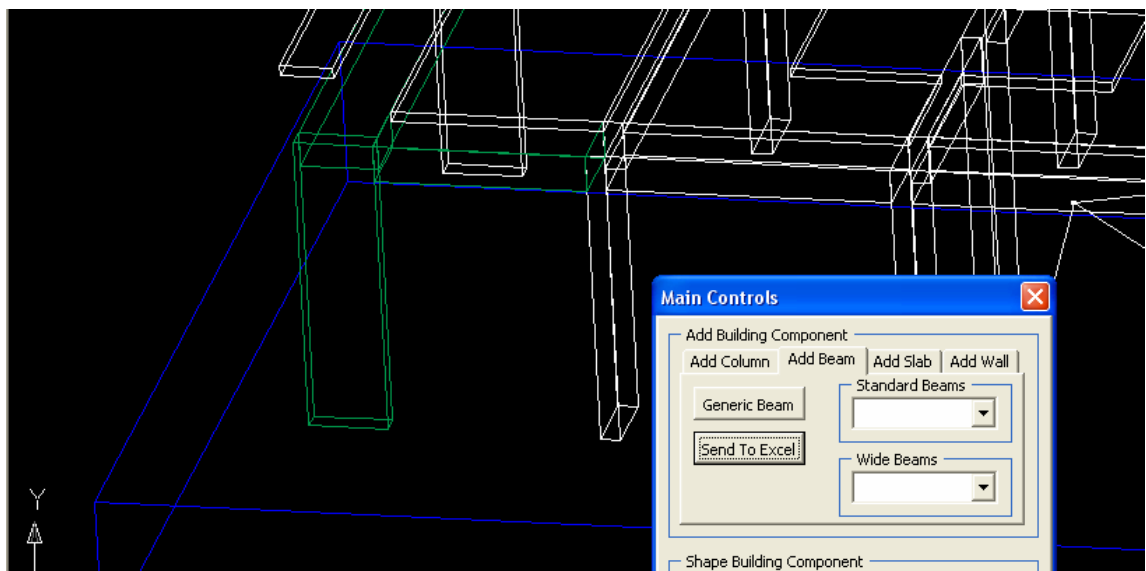


Figure 9.2.b. The software application is converting the colour and layer of selected building components into pre-specified settings in order to avoid double entries.

Project Name:

Kusadasi S. house

Date:

12.06.2008

Item	Material	Unit	Unit Price	Quantity	Cost	
1	Ground Floor Column A/1	C20	m3	10	0.530	5.303
2	First Floor Beam 1	C30	m3	10	0.672	6.724
3	First Floor Beam 2	C20	m3	10	1.615	16.154
4			m3			
5			m3			
6			m3			

Figure 9.2.c. The information entered in AutoCAD screen is transferred to the Excel along with the automatically calculated quantities.

44			m3			
45			m3			
46			m3			
47			m3			
48			m3			
49			m3			
50			m3			
Page Total:						28.181

Figure 9.2.d. At the bottom of the same page, the interim payment total is being generated.

The Excel file created by the model is configured as a standard bill of quantities sheet which is clear and easy to understand. Excel file format is a very common and popular data format. The text on Excel sheets can be exported to or exchanged by other applications. The values calculated by the code, during and after data exportation process are completely accurate provided that the 3D model was produced correctly.

9.2.4. Data Format Conflicts, Data Re-entry and Data Losses Avoidance

At the evaluation stage of this thesis it is now clear that this target has been achieved. VBA allows software designers to programme VBA enabled software applications to

control each others objects libraries. This means VBA enabled programs can use information created by another VBA enabled software application. The software created for the case study of this thesis was written in VBA. It successfully linked AutoCAD objects library with Excel in order to create the bills of quantities from 3D CAD models.

One of the outputs of the model created in this thesis is the 3D CAD model of the construction. It is created in AutoCAD's ".dwg" file format. The AutoCAD file format ".dwg" is recognised by many other software applications on the market but 3D models created by the current model can also be exported as the drawing exchange format ".dxf". Therefore, the model offers the data format flexibility needed by the industry as was aimed for at the beginning of this research.

The second output of the research is an Excel spreadsheet which contains the Bills of Quantities. Excel's ".xls" format is one of the most widely known data formats of today. The data stored in an Excel sheet can be accessed by VBA enabled programs. Alternatively, the data in an Excel sheet can be exported as various text formats. These features mean yhat, Excel spreadsheets also offer the data format flexibility needed by the industry which meets another objective of the current thesis.

Another major issue to avoid is the repetitive data entry problem. It is a common problem that occurs when the data collected from site is manually entered to various forms, and then this data is re-organised and re-entered to the computer programmes in order to benefit from automation. Through these re-entry and double-labour activities, some of the data is lost, which means that the time and money is wasted. In this thesis this problem was identified in Chapter 4. The proposed model captures the data using hand held digital cameras; which means that, the data is in digital format as it is collected. Once a digital image is uploaded to a PC, it is processed within the computer environment until the end of the process. Hence the model is successful in avoiding any double entries and unnecessary labour. The benefits gained from error reductions cannot be measured physically, however, since the manual pen and paper based data entry to a sheet is no longer necessary, it can be expected that human errors will be reduced or data losses during the process can be avoided.

9.3. Reactions and Comments from the Industry

Potential users of the proposed model are construction industry professionals and clients technical advisors. Informal telephone interviews and email correspondence has been made with representatives and clients' professional agents of the Turkish construction industry in order to receive feedback about the validity of the model. Positive and negative reactions given by the professionals are explained in the following sections. All of the people interviewed were already experienced in using AutoCAD and are well versed in contract management issues in Turkey. Therefore, they are familiar with traditional solutions to the construction progress measurement problem.

9.3.1. Positive Reactions

The proposed model received favourable comments in terms of practicality, reliability and user friendliness. Industry professionals and clients representatives both agreed that the model has the potential to reduce construction industry conflicts since the documentation created is easy to understand as well as being supported by visual materials such as digital images and 3D building CAD models.

The clients' representatives complained that traditionally they find it difficult to monitor contractors' progress on site. They also expressed dissatisfaction in traditional construction documentation since they find the bills of quantities inaccurate at almost all times in favour of contractors. Whilst the clients' side complained about exaggerated measurements of contractors, the contractors' representatives expressed that they have difficulties in convincing clients to pay for the work which has been achieved on site. As a result, both of the groups with conflicting interests found the proposed method useful in improving the quality of the construction documentation since the visual materials are available to support numbers and the automation offered within the model improves the integrity of the calculations.

9.3.2. Negative Reactions

Interviews revealed that the industry is primarily concerned with potential costs incurred due to the model. The proposed model requires investment in package software and personal training in order to be useful. These investments can affect the project management costs to a degree that smaller size contractors or temporary (short term) clients of the industry may find it to be unreasonable. This comment was answered by reminding that this is an investment to be done by the contractors' side and it is done only once. The same software and training will be used many times for different projects in order to distribute these extra costs between many different contracts. Hence the costs which have to be reflected on project management expenditure will be insubstantial. On clients' side, there is no need for any additional training of any kind, in fact, the pictures and 3D models mainly serve for inexperienced clients' clarity and convenience.

The package software to be invested is already being used commonly within the industry, so will often, not appear as additional costs. Therefore, whilst the model creates some minor extra costs, it should be seen as good value.

9.4. Conclusions

This chapter reported the evaluation methods and results of this thesis. According to this chapter, the thesis is classified as a quantitative research work which allows it to be evaluated by numerical comparisons. After comparing the manual measurement results against the outcomes of the case study done for testing the proposed model, it has been revealed that the proposed model can produce the 3D model of the construction with accurate sizes within similar mistake margins which can be achieved manually. The volumetric calculations derived from these 3D models are highly accurate. Spreadsheets produced with these data are correct and clear.

The imperfections detected in image 9.1 about the locations of the columns are the results of two main issues. Since the shifting of the column bases is uniform, it is the

result of imperfect camera location calculations. As a result, it can be reported that these calculations regarding to cameras relative location must be made by using more sophisticated software dedicated for photogrammetry, instead of VizRender which the current research has been using. The second issue is the fact that the measurements on the picture are done manually using a pointing device such as a mouse. This means that these manual measurements can have human errors in them almost similar to those measurements obtained on site. To help preventing this, integration of edge detection software to this model could improve the quality of these measurements.

Construction industry professionals gave favourable comments about the proposed model. They found the functions of the software application useful and suitable for their work. They agreed that the model has potential in reducing construction industry conflicts.

Chapter 10: Summary and Conclusions	182
10.1. <i>Introduction</i>	182
10.2. <i>Executive Summary of the Thesis</i>	182
10.3. <i>Conclusions of This Research</i>	185
10.3.1. Conclusion 1: Automation is needed in the Construction Industry	185
10.3.2. Conclusion 2: As-Built Data Must Be Collected Directly from Construction Sites	186
10.3.3. Conclusion 3: Method of Data Collection	186
10.3.4. Conclusion 4: Problems with Solely Photogrammetry Based Method	188
10.3.5. Conclusion 5: Improvements to the Model through Construction Knowledge	188
10.3.6. Results Gained	189
10.4. <i>Contribution of This Research to the Knowledge</i>	189
10.5. <i>Recommendations for the Future Work</i>	190
10.5.1. Introducing BIM to Progress Measurement	190
10.5.2. Linking the 4D Models with the Proposed Model	191
10.5.3. Integration of Further Construction Knowledge	191
10.5.4. Integration of Mobile Phone Technology	192

Chapter 10: Summary and Conclusions

10.1. Introduction

This chapter consists of four parts. The first part acts as a short executive summary. In this chapter, the aim is to summarise the general points of the thesis so that it can serve as a quick way of learning the scope of research for those people who don't have time to read the whole span of the dissertation. The second part of the chapter is aimed at reporting the consequences of the thesis and the insight gained from it and thus providing an evaluative perspective. The third part explains the contribution of this thesis to current knowledge. Under this heading, new knowledge introduced by this research is explained.

10.2. Executive Summary of the Thesis

To be able to reduce conflicts and improve the communication within the project team, more visual aid is essential. In order to provide the visual aid for the as-built situation of the project, both academia and the industry are resorting to computer based automation and 3D CAD models. This thesis is one of the attempts within academia aimed at integrating computer based solutions to monitor and visualize construction progress.

What makes this study different from others is the fact that this research is about measuring the current status of the progress without resorting to a building information model. While design information is subject to change during the construction stage, schedules and budgets are subject to considerable levels of variation. This thesis is about measuring the current status of the construction by relying on the current information coming directly from the construction site. Therefore; it does not rely on planning stage information, it actually constantly monitors the viability of it. Such an approach is therefore applicable to situations where no computer based building design model has been developed, particularly in refurbishment projects where existing structures come without any computer based design data.

Current progress measurement tools are partially automated and as such they are cumbersome and hence project managers often resort to judgement and shortcuts. Partial and independent automation attempts also create the phenomenon called “islands of automation”. With regard to monitoring schedule and cost variations these methods offer various solutions but they lack a simple method for data collection from the construction sites regarding progress. In this thesis it is argued how a simpler method of 3D data collection from construction sites can help these methods produce results more easily and at a higher accuracy.

Construction sites can be dangerous, dark, cold, inaccessible and inhospitable places. This makes it very difficult to obtain data from them, particularly on the progress achieved and the costs incurred to date. The result of this is a lack of up to date information about the current status of the construction.

Such problems, together with the unpredictability within the industry, make construction a risky endeavour for clients. Lots of conflicts occur because of disagreements between construction professionals and clients who can not communicate with the same terminology. Clients are often inexperienced and not familiar with construction industry drawings. Within the scope of this research, the majority of these problems are reviewed. The ways in which the proposed model can increase communication and mutual understanding between the clients of the industry through visualisation, 3D models, and digital images of the progress on site are elaborated.

In this thesis it is shown that the research method of this work has hardly any qualitative research strategies. The main experiment of the thesis uses physical quantitative measurement methods for justification via photogrammetry and construction knowledge.

Camera models are defined to approximately calculate the mathematical relation between the images and the objects on the scene. The co-linearity rule means the focal point; lens centre and the scene point of a camera are on the same line during the photo

snapshot. Using this rule, measurements can be taken from the images in order to create accurate 3D models of the objects. This photogrammetry based technique when applied on its own, is found to be slow, difficult and time consuming. Therefore, the research proposes augmentation of this technique with the use of construction knowledge, and VBA automation.

The design criteria of the building components is defined by the local construction regulations and limited by the properties of the materials used. Integration of the construction knowledge to the proposed model can reduce the need for photogrammetric measurements and offer the operators speed and convenience in their 3D modelling operations. Columns, beams and floors are all dimensioned by Turkish building structure regulations. These regulations impose various minimum values that can be used for the structural design. Practical needs such as hiding the columns between the walls contribute to the design of the structural components. Knowing these minimum values and the functional requirements of the housing construction provides users with a manageable list of alternative building elements that can help in creating the 3D models of the buildings from photos.

The final product of the thesis is introduced and an example 3D model created from an image imported to AutoCAD. The experiment showed that the application generated for this thesis can produce accurate 3D models of building constructions. These models can be used to export quantities of the work done on site to Excel spreadsheets in order to create priced bills of quantities. The generation of 3D models by this application was fast and easy compared to conventional surveying methods such as going to the construction site and literally measuring the works.

The thesis is classified as a quantitative research work; therefore it can be evaluated by numeric comparisons. After comparing the manual measurement results against the outcomes of the case study done for testing the proposed model, it has been revealed that the proposed model can produce the 3D model of the construction with accurate sizes within similar mistake margins which can be achieved with manual surveying

methods. The volumetric calculations derived from these 3D models are highly accurate. Spreadsheets produced with these data are correct and clear.

10.3. Conclusions of This Research

Upon completion of this thesis, the new insight gained from the research, and the possible consequences of the work done will be explained under this heading. Under this topic, no new information is given. Only the conclusions drawn from the work subject of this thesis are mentioned.

10.3.1. Conclusion 1: Automation is needed in the Construction Industry

The first conclusion of the literature review of this thesis is about the need for automation in the construction industry. The importance of the construction industry is recognised by various researchers and is well documented. This research reviewed the reasons of the importance of the industry and attempted to contribute to the construction automation agenda via the automation of construction progress measurement.

The current techniques and solutions used by the industry were reviewed and were found to be isolated from each other and cause too many data re-entries. Some of the other schedule monitoring methods are partially automated but are less useful as they lack accurate as-built data. Therefore, a gap amongst the solutions available to project team members was identified and a methodology is proposed to fill this gap. Whilst trying to address this problem, the research revealed new conclusions as described in the following sections.

10.3.2. Conclusion 2: As-Built Data Must Be Collected Directly from Construction Sites

There are two main approaches for where to obtain the data needed for construction progress measurement. Data can be taken from the planning and design stage such as in the form of design drawings, or it can be collected directly from the site. The first approach relies on the assumption that the project drawings are strictly and accurately adhered to or that the progress ran according to schedule. Provided that these assumptions are true, these research projects (4D models) can show the project team how the construction will look in 3D, and how much cost will be incurred at any given time of the project. This data is valuable because it can be compared with the real occurrence in order to take corrective action with schedule and cost variances.

The problem with this type of approach is that it does not offer any solution for calculating the real occurrence on the site. Any real data needed for comparison must be obtained by traditional surveying methods or by intelligent assumptions. To resolve these problems, the second approach in the construction financial management must be adopted. According to this approach, the data to be compared against the planning stage data must be collected directly from the construction site. Currently these methods explored by academia are full automation via computer vision, semi automation with photogrammetry or computer vision and laser scanning applications. After a comprehensive review of each approach, this research went for the semi-automatic photogrammetry based method. The reasons for this decision are discussed in the following sections.

10.3.3. Conclusion 3: Method of Data Collection

These three methods reviewed for capturing progress from the construction site have different advantages and short comings. The outcome of the literature review reveals the following conclusions:

The laser scanner based method requires delicate equipment to be used within the construction site under hostile conditions. The product of the laser scanning is a cloud of 3D points and it needs further editing before it can be used for CAD modelling. The point clouds can have wide gaps in them due to the occlusion of scaffolding around the perimeter of the building, parked cars or trees between the target and the scanner. In addition to that, the reliability of the scanning depends heavily on weather conditions. The accuracy of the device used can be affected by weather conditions. While the method offers significant convenience for 3D data collection, due to the fact that construction is an open air activity, the laser scanner technology at its current status seems unsuitable for periodic measurements needed for the purpose of this thesis.

The second approach is full automation. The ultimate challenge in progress measurement studies is being able to obtain construction progress fully automatically from construction sites by means of computer vision. Full automation via the Iconic Recognition based research path gives promising results for fulfilling this challenge. However this method also has disadvantages. Occlusions on the construction site make it impossible to capture every detail of the progress. The method also relies on measuring the proportions of the distances of pixels from each other. Therefore; if a garage door on the site happens to have the same dimensional proportions as scaffolding units, this method can register the rectangular scaffolding module as the garage door. Such problems lead to the conclusion that full automation via computer vision is not ready to offer the optimum solution to the data collection problem on construction sites.

The third alternative is the photogrammetry based semi-automatic data collection method. This method uses digital images for surveying and progress measurement purposes. Due to the manual involvement of the operator, it is not likely to fail in adverse weather conditions, or encounter mistakes that a fully automated system can make. However; a solely photogrammetry based method has its short comings too.

10.3.4. Conclusion 4: Problems with Solely Photogrammetry Based Method

A solely photogrammetry based method does not lend itself to fast and practical solutions. It gives accurate 3D results from digital images and this information can be exported to spreadsheets to be used for progress measurement purposes, but the time and effort invested to take the measurements purely by photogrammetry applications is not feasible. It can be used for construction progress measurement purposes only if it is improved.

Since the photogrammetry based approach is slow and impractical this research offers improvements to it via construction knowledge and further automation. Conclusions regarding to proposed improvements are explained in the following section.

10.3.5. Conclusion 5: Improvements to the Model through Construction Knowledge

Construction industries are strictly constrained by building regulations and these regulations contribute to the physical shape of the buildings. Structural elements are designed according to the current regulations in every country.

In addition to building regulations, the materials used on site are standard products with a limited variety of dimensions. Based on these two facts, construction knowledge can contribute to the photogrammetry based model to make it faster and easier to use. This research has used Turkish Building Industry regulations to assist 3D modelling operations with photogrammetry. When the known dimensions of the building elements are used in the operation, time and effort needed to complete the 3D model are reduced significantly. This allows the generation of a semi automatic photogrammetry and construction knowledge based system for the resolution of the construction progress measurement problem.

10.3.6. Results Gained

Using the photogrammetry and construction knowledge, a prototype computer program was created using the Visual Basic for Applications (VBA) programming language. The results of the case study using the new application supported the theory about the photogrammetry and construction knowledge based approach to the progress measurement problem. A 3D model of a building under construction can be generated easily with very little input using the new application. The data on the 3D model can instantly be transferred to Excel automatically in order to produce bills of quantities quickly and accurately compared to the traditional surveying methods. The operator can use cheap digital cameras, and once the images are captured, the measurement process can take place within the convenience of the office space. The results are all within the computer environment, therefore can be shared or exchanged via network facilities or the World Wide Web. The experience gained from a project can be reused for knowledge management purposes. Results of the measurements are produced from the digital images; therefore the digital images are available to support information regarding the process. Conflicts are less likely to occur as clients of the construction industry are more likely to be satisfied by the business. If there are variations on the schedule or with the cost plans, it can be detected early in the process in order to take corrective action, thereby reducing the chance of losing money or time.

10.4. Contribution of This Research to the Knowledge

This research introduces a construction progress measurement method to create 3D CAD models of buildings with almost no need for on-site measurements or manual surveying. Although the proposed data collection method is partially photogrammetry based. It is different from previous photogrammetry based data collection methods because it introduces building regulations and construction knowledge to the measurement processes. For example the method developed by Vosselman, introduces a photogrammetry based semi-automatic reconstruction of industrial installations (Vosselman 2001). It also aims to use simple geometric objects to create more complex geometries, but the target geometries are all made of standard pipes and fittings or

machinery parts. Therefore, it is different from the proposed method because the building design is not limited to assembled, standard (manufactured) components. Building components are not usually selected from the catalogues, they are not off-the-shelf objects and they are shaped with more complex mechanisms and preferences such as aesthetics, material limitations, local construction traditions, and building regulations. This research introduces such mechanisms into reverse engineering of construction milestones in 3D CAD modelling, in order to calculate interim and final payments of the contractors.

This research is also different from 4D modelling techniques. It is only focussed on the current status of the construction site. Data is collected directly from the site and the calculations are based on this up-to-date data. These calculations can be used to make projections about the future direction of the construction progress; however, the model itself is aimed at accurately measuring the current level of the construction without using planning and design stage information.

10.5. Recommendations for the Future Work

The literature review revealed that one of the current mainstream directions of computer integration to construction is focussed on the construction progress measurement area. Regardless of the methods used for measuring the progress on the site, the first suggestion for future research in this area is to improve the role of computer automation further. The potential to achieve this exists via several different ways which are explained in the following sections.

10.5.1. Introducing BIM to Progress Measurement

Building Information Model (BIM) is a new CAD concept. Computer programs such as Revit, ArchiCAD, and VectorWorks can not only offer a 3D model representation of the building designs, but also contain information regarding geometry, spatial relationships, geographic information, quantities and properties of building components.

Such programs are still new and computers are not powerful enough to handle all the possible information a BIM can require. Nevertheless, using a BIM instead of an AutoCAD model can greatly improve the capabilities of the proposed model. In order to use such models in the proposed method, the program they are produced must be VBA (or a similar data exchange method) enabled. They also need to have an advanced, adjustable virtual camera functionality.

10.5.2. Linking the 4D Models with the Proposed Model

A group of researchers have worked on 4D or nD models in order to model and animate construction progress visually. The results from these research projects were successful in answering the question “What will be the cost and progress status of a construction for any given time, if everything goes according to schedule?” Since project planning and schedule data were linked with 3D design data, it was possible to offer the 3D models and bills of quantities automatically. This data assumed that the projects went according to schedule. Since this PhD thesis created a model to offer the actual occurrences on the site, these two methods could be connected. The cost and schedule variances must be calculated as the next step. 4D models can visually show the planned status of the constructions for any specified date. They can also produce the bills of quantities automatically by using the planning stage data. The model created for this thesis can produce the same results by using digital images captured directly from the construction site. Differences between the actual conditions on the site and the 4D model data would give the schedule and cost variances. Further automation can be gained by merging the two approaches to obtain this cost and schedule variances.

10.5.3. Integration of Further Construction Knowledge

Construction knowledge can be further introduced to increase the role of computer automation in progress measurement operations. At the current stage of the study, only the minimum and maximum values of the structural elements were taken from the building regulations. A statistical approach was also introduced to guide the operator with regard to how often a dimension of a structural element is likely to be seen within

the industry. In addition to that, structural design methods could be further introduced to the 3D modelling operations. Currently the model in this PhD is both photogrammetry and construction knowledge based. In such an alternative approach, the model would be much less photogrammetry based and much more construction knowledge based. This may increase the amount of automation introduced to the measurement operations. As an example, one challenge in this area would be to create, a model which calculates the beam and column dimensions automatically using data on the digital images, resulting in very little or no photogrammetric input.

10.5.4. Integration of Mobile Phone Technology

Academia is currently busy integrating computer technologies for construction automation while rapid developments are taking place in mobile phone related technologies. Bill Gates revealed that Microsoft researchers are currently working on camera phone technologies that will use image recognition technologies to give users information about the images taken by these camera phones. Similar technologies are likely to be used for site management and progress measurement activities. Mobile phones can overcome some of the problems caused by the technologies used in fully automated construction progress measurement techniques. For example the occlusion of fixed cameras can be overcome by mobile phones. Mobile phone technologies could be further investigated and included for any future computer integrated project management studies since there is an unused potential waiting to be explored in the area of mobile phone technologies.

List of References

194

List of References

3Dmapper. (2003). "Desktop Digital Photogrammetry System (DDPS)." from <http://www.3dmapper.com/3ddemos.htm>.

Aka, I., F. Keskinel, et al. (1990). Introduction to the Reinforced Concrete Istanbul, Birsen Publishing.

Alshawi, M. and I. Faraj (1995). Integrating CAD and Virtual Reality in Construction. Virtual Reality and Rapid Prototyping for Engineering. Salford.

Alshawi, M. and J. Suliman (1995). Applying Structured Process Analysis to Site Layout Planning. The 6th International Conference on Computing in Civil and Building Engineering Berlin.

Alshawi, M. and J. Underwood (1996). "Improving the constructability of a design solution through an integrated system." The International Journal of Engineering, Construction and Architectural Management **3**(1&2): 15-22.

Aouad, G., M. Betts, et al. (1994). Integration of Construction Information (ICON) Final Report- Integrated Database for Design, Procurement and Management of Construction. Salford, University of Salford.

Aouad, G., T. Child, et al. (1997). Open Systems for Construction (OSCON) Draft Industrial Report Salford, University of Salford.

References

Aouad, G., J. Kirkham, et al. (1995). "The Conceptual Modelling of Construction Management Information." Automation in Construction **3**: 267-282.

Arayici, y. (2007). "An approach for real world data modelling with the 3D terrestrial laser scanner for built environment " Automation in Construction **16**(6): 816-829.

Arayici, Y., V. Ahmed, et al. (2006). A Requirements Engineering Framework For Integrated Systems Development For The Construction Industry, itcon.org.

Arayici, Y. and A. Hamilton (2005). Modeling 3D Scanned Data to Visualise the Built Environment. 9. International Conference on Information Visualisation. Manchester.

Arditi, D. and T. Pattanakitchamroon (2005). "Selecting a delay analysis method in resolving construction claims " International Journal of Project Management **24**(2): 145-155.

Aydinoğlu, M. N. (1998). Regulation About the Buildings within the Disaster Zones. T. M. o. W. a. Housing.

Bal, İ. E., H. Crowley, et al. (2006). "Detailed assessment of structural characteristics of Turkish RC building stock for loss assessment models." Soil Dynamics and Earthquake Engineering.

Barnes, J., K. Conrad, et al. (2005). "Generalizability and Transferability." Writing@CSU Retrieved 05.01.2008, from <http://writing.colostate.edu/guides/research/gentrans/>.

References

Bayrak, T. and A. Kaka (2004). Evaluation of Digital Photogrammetry and 3D CAD Modelling Applications in Construction Management. ARCOM 2004. Edinburgh.

Bayrak, T. and A. Kaka (2005). CAD Based, Semi-automatic Data Acquisition Method for Construction Management CONVR 2005. Durham.

Bowden, S., A. Dorr, et al. (2005). "Mobile ICT support for construction process improvement " Automation in Construction **15**(5).

Bryan, P. (2003). "An Addendum to the Metric Survey Specification for English Heritage." English Heritage **11**.

Carter, K. and C. Fortune (2004). Issues With Data Collection Methods in Construction Management Research. ARCOM. Edinburgh.

Cheng, M.-Y. and J.-C. Chen (2001). "Integrating barcode and GIS for monitoring construction progress " Automation in Construction **11**(1): 23-33.

Cheung, S. O. and K. T. W. Yiu (2005). "A study of construction mediator tactics—Part I: Taxonomies of dispute sources, mediator tactics and mediation outcomes

" Building and Environment **42**(2): 752-761.

Cioffi, D. F. (2005). "Designing project management: A scientific notation and an improved formalism for earned value calculations " International Journal of Project Management **24**(2): 136- 144.

References

Clark, J. E. (2002). VBA for AutoCAD. Upper Saddle River, Prentice-Hall.

Coltekin, A. (2006). Foveation for 3D Visualiazation and Stereo Imaging. Photogrammetry and Remote Sensing. Helsinki, Helsinki University of Technology. **PhD**.

Cooper, G., G. Aouad, et al. (1993). Incorporating Alternative Perspectives in a Single Information Model: The ICON Project Analysis Method. The Workshop on Models for Computer Integrated Construction. Finland.

Davidson, I. N. and M. J. Skibniewski (1995). "Simulation of automated data collection in buildings." Journal of Computing in Civil Engineering **9**(1): 9-20.

Dawood, N., A. Akinsola, et al. (2002). "Development of automated communication of system for managing site information using internet technology " Automation in Construction **11**(5): 557-572.

Dawood, N., D. Scott, et al. (2002). The Virtual Construction Site (VIRCON) Tools: An Industrial Evaluation. nD Modelling Road Map: A Vision for nD- Enabled Construction. Manchester, UK, Centre of Construction Innovation.

Dawood, N., E. Sriprasert, et al. (2001). VIRCON Database Quick Reference. Middlesbrough, University of Teesside.

Dean, J. (2007). A Study of the A.I. Wet Concrete Manufacturing Processes and the Impact of Automation on the Supply Chain. Middlesbrough, University of Teesside. **PhD**: 69-70.

References

Dennis, J. C. (2003). The Extent of Use of Computer Software Applications in the Project Management Process, a Comparison Between United Kingdom and Jamaica. School of the Built Environment. Edinburgh, Heriot Watt. **MSc Thesis:** 90, 91.

Edum-Fotwe, F. T., A. D. F. Price, et al. (1996). Research Methods Versus Methodology: Achieving Quality in Scholarly Research for Construction Management. ARCOM.

Egan, J. (1998). Rethinking Construction, Department of Trade and Industry.

EOS. (2007). "Photomodeller for Architecture and Preservation ", 2008, from http://www.photomodeler.com/applications/architecture_and_preservation.htm.

Faraj, I. and M. Alshawhi (1999). "A Modularised Integrated Computer Environment for the Construction Industry: SPACE." Journal of Information Technology in Construction **4**(1999): 37-52.

Fellows, R. and A. Liu (2003). Research Methods for Construction, Blackwell Publishing.

Fleming, Q. W. and J. M. Koppelman (2000). Earned Value Project Management. Pennsylvania, Project Management Institute.

Gürer, A. and M. Bayrak (2005). "Relation between electrical resistivity and earthquake generation in the crust of West Anatolia, Turkey." Tectonophysics **445**(1-2).

Hadwan, M., A. P. Kaka, et al. (2000). "Application of photogrammetry in lighting calculations for obstructed interiors." Journal of Lighting Research Technology **32**(1).

References

Haniff, A. (2002). Building Case Study, Standard Life House. Heriot-Watt University School of the Built Environment.

Hannus, M., H. Penttila, et al. (1998). "Islands of Automation in Construction ", from <http://www.cic.vtt.fi/hannus/islands/>

Hassan, Z. (1997). CONPLAN: Construction Planning and Buildability Evaluation in an Integrated and Intelligence Construction Environment. Department of Surveying. Salford, University of Salford. **PhD**.

Helen, S. N., F. Pena-Mora, et al. (2007). "Dynamic Conflict Management in Large-Scale Design and Construction Projects." Journal of Management in Engineering **23**(2): 52-66.

Howell, G. A. (1999). What is Lean Construction. Seventh Annual Conference of the International Group for Lean Construction, IGLC-7. Berkeley, CA

HSE. (2007). "Health and Safety in the Construction Industry." Retrieved 19.05.2007, from <http://www.hse.gov.uk/construction/index.htm>.

Huttenlocher, D., G. Klanderman, et al. (1993). "Comparing Images Using the Hausdorff Distance." IEEE Transactions on Pattern Analysis and Machine Intelligence **5**(9).

Hwee, N. G. and R. L. K. Tiong (2002). "Model on cash flow forecasting and risk analysis for contracting firms " International Journal of Project Management **20**(5): 351-363

References

Kaka, A. (1996). "Towards more flexible and accurate cash flow forecasting." Construction Management and Economics **14**: 35-44.

Kaka, A. (2003). Cost Planning and Control. Project Management Theory and Practice Notes. Edinburgh, Heriot Watt University SBE.

Kartam, N. A. (1994). "ISICAD: Interactive system for integrating CAD and computer-based construction systems." Microcomputers and Civil Engineering **Vol.9**: 41-51.

Kerzner, H. (2003). Project Management, A Systems Approach to Planning, Scheduling, and Controlling. Berea- Ohio, John Wiley & Sons, Inc.

Knight, M. and A. Kaka (1998). Application of Computer Based Photogrammetric Techniques to Building Modelling and Costing. ECPPM's98- The second European conference on product and process modelling in the building industry. Bre/ UK.

Lang, F. and W. Forstner (1996). "3D-City Modeling with a Digital One-Eye Stereo System." International Archives of Photogrammetry and Remote Sensing **31**: 415-420.

Li, H., Z. Chen, et al. (2004). "Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency " Automation in Construction **14**(3): 323-331.

Lockyer, K. and J. Gordon (1991). Critical Path Analysis, and Other Project Network Techniques. London, Financial Times Management.

References

Mahdi, I. M. (2002). "A new LSM approach for planning repetitive housing projects " International Journal of Project Management **22**(4): 339-346.

Marir, F., G. Aouad, et al. (1998). "OSCONCAD: A Model-Based CAD System Integrated With Computer Applications " Electronic Journal of Information Technology in Construction **3**: 25/44.

Marshall-Ponting, A. J. and G. Aouad (2004). "An nD modelling approach to improve communication processes for construction " Automation in Construction **14**(3): 311-321.

McFedries, P. (2004). Absolute Beginner's Guide to VBA. USA, QUE.

Miles, M. B. and A. M. Huberman (1994). Qualitative data analysis, Thousand Oaks: Sage Publications.

Mortenson, M. E. (1997). Geometric Modelling. New York, John Willey & Sons.

Navon, R. (2005). "Automated Project Performance Control (APPC) of Construction Projects." Automation in Construction **14**(4): 467-476.

Navon, R. and E. Goldschmidt (2003). "Can labor inputs be measured and controlled automatically?" Journal of Construction Engineering and Management **129**(4): 437-445.

Navon, R. and R. Sacks (2006). "Assessing research issues in Automated Project Performance Control (APPC)." Automation in Construction **16**(4): 471-484.

References

Navon, R. and Y. Shpatnitsky (2005). "Field experiments in automated monitoring of road construction." Journal of Construction Engineering and Management **131**(4): 487-493.

Neill, J. (2007). "Qualitative versus Quantitative Research: Key Points in a Classic Debate." Research Methods Retrieved 05.01.2008, from <http://wilderdom.com/research/QualitativeVersusQuantitativeResearch.html>.

North, S., G. Winch, et al. (2003). Technical Evaluation: VIRCON Task 12 Raport. Manchester, Centre for Civil and Construction Engineering UMIST.

Orbay, A. (2005). Reinforced Concrete Buildings 1. Istanbul, Birsen Basim Yayin.

Plets, R. M. K., J. K. Dix, et al. (2006). "3D reconstruction of a shallow archaeological site from high-resolution acoustic imagery: The Grace Dieu " Applied Acoustics.

Poyet, P. (1994). ATLAS Integration Tools. 1st ECPPM Conference. Dresden Germany.

Putra, C. W. (1998). Construction Application Protocol for Data Transfer: A Building Data Model. Department of Surveying. Salford, University of Salford. **PhD**.

RealViz. (2008). "ImageModeler Getting Started Tutorials." from <http://imagemodeler.realviz.com/photomodeling-software-tutorials/modeling-tutorials-imagemodeler-8.php>.

References

Saidi, K. S., A. M. Lytle, et al. (2003). Report of the NIST workshop on data exchange standards at the construction job site. ISARC— 20th International Symposium on Automation and Robotics in Construction. Technische Universiteit Eindhoven, Eindhoven, The Netherlands

SBE, H.-W. U. (2007). Research Ethical Guidelines. H.-W. U. SBE.

Seymour, D. and J. Rooke (1995). "The Culture of the Industry and the Culture of Research." Construction Management and Economics **13**: 511-523.

Shapiro, L. S. (1995). Affine Analysis of Image Sequences CUP.

Shirai, Y. (1987). Three Dimensional Computer Vision. Ibaraki/ Japan, Springer-Verlag.

Smith, M. L. and L. N. Smith (2007). "Computer Vision Applications." Image and Vision Computing **25**(7): 1035-1036.

Styliadis, A. D. (2006). "Digital documentation of historical buildings with 3-d modeling functionality." Automation in Construction **16**(4): 498-510.

Sutphin, J. (2004). AutoCAD 2004 VBA "A Programmer's Reference". USA, Apress.

References

Tangelder, J., P. Ermes, et al. (2003). "CAD- Based Photogrammetry for Reverse Engineering of Industrial Installations." Computer- Aided Civil and Infrasutructure Engineering **18**: 264-274.

Tolman, F. P. (1999). "Product modeling standards for the building and construction industry: past, present and future " Automation in Construction **8**(3): 227-235.

Trochim, W. M. K. (2006, 10/20/2006). "Qualitative Measures." Research Methods Knowledge Base Retrieved 05.01.2008, from <http://www.socialresearchmethods.net/kb/qual.php>.

Trucco, E. and A. Kaka (2004). "A Framework for Automatic Progress Assessment on Construction Sites Using Computer Vision."

Trucco, E. and A. Verri (1998). Introductory Techniques for 3D Computer Vision, Prentice-Hall.

TSI (2001). Requirements for design and construction of reinforced concrete structures Turkish Standards Institute. **TS 500/T1**.

TSI (2003). Construction Materials Regulations, Turkish Standards Institute. **TS EN 771-1**.

Uyan, I. (2006). "Hollow Tile Floor Details." 2007, from <http://www.insaatforumu.com/forum/showthread.php?t=879>.

References

Vandevoorde, S. and M. Vanhoucke (2006). "A Comparison of Different Project Duration Forecasting Methods Using Earned Value Metrics." International Journal of Project Management **24**: 289-302.

Vosselman, G. (2001). "Semi-automatic CAD Based Reconstruction of Industrial Installations." Künstliche Intelligenz **4**: 23-27.

Wideman, M. (1994). "Applying Resource Loading, Production and Learning Curves to Construction: A Pragmatic Approach." Canadian Journal of Civil Engineering **21**: 939-953.

Wolf, P. R. (1983). Elements of Photogrammetry, McGraw-Hill, Inc.

Yeo, K. T. and J. H. Ning (2006). "Managing uncertainty in major equipment procurement in engineering projects." European Journal of Operational Research **171**(1).

Yilmaz, H. M., M. Yakar, et al. (2007). "Documentation of historical caravansaries by digital close range photogrammetry " Automation in Construction **17**(4): 489-498

Yin, S. Y. L., H. P. Tserng, et al. (2007). "A model of integrating the cycle of construction knowledge flows: Lessons learned in Taiwan " Automation in Construction **17**(5): 536-549.

Zlatanova, S. and F. A. v. d. Heuvel 3d City Modelling For Mobile Augmented Reality. Proceedings of the International Symposium on architectural photogrammetry, Potsdam, Germany.

Appendix 1. VBA Code Used in the Application	207
10.1. <i>Module Level Codes</i>	207
10.2. <i>Sub-procedures</i>	211

Appendix 1. VBA Code Used in the Application

10.1. Module Level Codes

"Layer related

Public Concrete As AcadLayer

Public RedBrick As AcadLayer

"Related to excel

Public QuantityTable As Excel.Workbook

Public AppExcel As Excel.Application

Public NewWorkbook As Excel.Workbook

Public FirstWorksheet As Excel.Worksheet

Public ProjectName As String

Public ProjectDate As String

Public ColNo As Integer

Public RowNo As Integer

"visual setup related

Public ImageView As AcadView

Public ActVport As AcadViewport

Public ActUCS As AcadUCS

Public PeakPoint As Variant

Sub FindPeakPoint()

 ThisDrawing.ActiveSpace = acModelSpace

 Set ImageView = ThisDrawing.Views.Item(1)

 Set ActVport = ThisDrawing.ActiveViewport

 Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(1)

 ActVport.SetView ImageView

 ThisDrawing.ActiveViewport = ActVport

 ThisDrawing.ActiveUCS = ActUCS

 With ThisDrawing.Utility

 PeakPoint = .GetPoint(, vbCr & "Enter the Focal point of the image: ")

 End With

 ComboBox1_Activate

 ComboBox2_Activate

 ComboBox3_Activate

 ComboBox4_Activate

 ComboBox5_Activate

 ComboBox6_Activate

 ComboBox7_Activate

 ComboBox8_Activate

```
"Start Excel and save the template as a new sheet

If QuantityTable Is Nothing Then
    Set QuantityTable = Excel.Application.Workbooks.Open("D:\SBE Related\VBA
Excercises\Blank List of Quantities\List of quantities.xls")
    QuantityTable.SaveAs "D:\SBE Related\VBA Excercises\Blank List of
Quantities\List of quantities 2.xls"

" Create a new workbook and identfy the first sheet
    Set NewWorkbook = GetObject("D:\SBE Related\VBA Excercises\Blank List of
Quantities\List of quantities 2.xls")
    Set FirstWorksheet = NewWorkbook.Worksheets(1)

Else: QuantityTable.Application.Visible = True

End If

"Write project name and date
    With ThisDrawing.Utility
        ProjectName = .GetString(True, vbCr & "Enter the Project Name: ")
    End With

FirstWorksheet.Cells(1, 3).Value = ProjectName

    With ThisDrawing.Utility
        ProjectDate = .GetString(True, vbCr & "Enter the Interim/Final Payment
Date: ")
    End With

FirstWorksheet.Cells(2, 3).Value = ProjectDate

RowNo = ActiveCell.Row
ColNo = ActiveCell.Column

NewWorkbook.Application.Visible = True

Set Concrete = ThisDrawing.Layers.Add("Concrete")
Concrete.color = 114 "dark green

Set RedBrick = ThisDrawing.Layers.Add("RedBrick")
RedBrick.color = 30 "Brick red

Main_Controls.Show
```

End Sub

Private Sub ComboBox1_Activate()

With Main_Controls.ComboBox1

.AddItem "200/500 mm"

.AddItem "250/400 mm"

.AddItem "250/500 mm"

.AddItem "250/600 mm"

.AddItem "250/700 mm"

.AddItem "250/800 mm"

.AddItem "300/400 mm"

.AddItem "300/500 mm"

.AddItem "300/600 mm"

.AddItem "300/700 mm"

.AddItem "300/800 mm"

End With

End Sub

Private Sub ComboBox2_Activate()

With Main_Controls.ComboBox2

.AddItem "h = 270 mm"

.AddItem "h = 300 mm"

.AddItem "h = 350 mm"

.AddItem "h = 370 mm"

.AddItem "h = 400 mm"

End With

End Sub

Private Sub ComboBox3_Activate()

With Main_Controls.ComboBox3

.AddItem "h = 80 mm"

.AddItem "h = 100 mm"

.AddItem "h = 120 mm"

.AddItem "h = 150 mm"

.AddItem "h = 200 mm"

End With

End Sub

Private Sub ComboBox4_Activate()

With Main_Controls.ComboBox4

```
.AddItem "h = 200 mm"  
.AddItem "h = 230 mm"  
.AddItem "h = 250 mm"  
.AddItem "h = 270 mm"  
.AddItem "h = 300 mm"  
.AddItem "h = 330 mm"
```

End With

End Sub

Private Sub ComboBox5_Activate()

With Main_Controls.ComboBox5

```
.AddItem "200/600 mm"  
.AddItem "200/800 mm"  
.AddItem "200/1000 mm"  
.AddItem "250/300 mm"  
.AddItem "250/400 mm"  
.AddItem "250/500 mm"  
.AddItem "250/600 mm"  
.AddItem "250/700 mm"  
.AddItem "250/800 mm"  
.AddItem "250/1000 mm"  
.AddItem "300/300 mm"  
.AddItem "300/400 mm"  
.AddItem "300/500 mm"  
.AddItem "300/600 mm"  
.AddItem "300/700 mm"  
.AddItem "300/800 mm"  
.AddItem "400/400 mm"  
.AddItem "400/500 mm"  
.AddItem "400/600 mm"
```

End With

End Sub

Private Sub ComboBox6_Activate()

With Main_Controls.ComboBox6

```
.AddItem "d = 300 mm"
```



```
.AddItem "d = 400 mm"  
.AddItem "d = 500 mm"  
.AddItem "d = 600 mm"
```

```
End With  
End Sub
```

```
Private Sub ComboBox7_Activate()
```

```
With Main_Controls.ComboBox7
```

```
.AddItem "w = 85 mm"  
.AddItem "w = 135 mm"  
.AddItem "w = 190 mm"
```

```
End With  
End Sub
```

```
Private Sub ComboBox8_Activate()
```

```
With Main_Controls.ComboBox8
```

```
.AddItem "w = 75 mm"  
.AddItem "w = 80 mm"  
.AddItem "w = 85 mm"  
.AddItem "w = 90 mm"  
.AddItem "w = 95 mm"  
.AddItem "w = 100 mm"
```

```
End With  
End Sub
```

10.2. Sub-procedures

```
Option Explicit
```

```
Private Sub ComboBox1_Click()
```

```
Dim X As Double  
Dim Y As Double  
Dim ColumnLength As Variant
```

```
Select Case ComboBox1.Text
```

```
Case "200/500 mm"
```

X = 200

Y = 500

Case "250/400 mm"

X = 250

Y = 400

Case "250/500 mm"

X = 250

Y = 500

Case "250/600 mm"

X = 250

Y = 600

Case "250/700 mm"

X = 250

Y = 700

Case "250/800 mm"

X = 250

Y = 800

Case "300/400 mm"

X = 250

Y = 400

Case "300/500 mm"

X = 250

Y = 500

Case "300/600 mm"

X = 250

Y = 600

Case "300/700 mm"

X = 250

Y = 700

Case "300/800 mm"

X = 250

Y = 800

End Select

"MsgBox X & Y

Main_Controls.Hide

Dim Building3D As AcadView

```
Dim ActVport As AcadViewport
Dim ActUCS As AcadUCS
    ThisDrawing.ActiveSpace = acModelSpace
    Set Building3D = ThisDrawing.Views.Item(2)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
    ActVport.SetView Building3D
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS

Dim BeamStartWCS As Variant
Dim BeamStartBCS As Variant

Dim BeamEndWCS As Variant
Dim BeamEndBCS As Variant

Dim BeamLenght As Double

With ThisDrawing.Utility

    BeamStartWCS = .GetPoint(, vbCr & "Pick the Beam Start Point: ")
    BeamStartBCS = .TranslateCoordinates(BeamStartWCS, acWorld, acUCS, False)

    BeamEndWCS = .GetPoint(, vbCr & "Pick the Beam End Point: ")
    BeamEndBCS = .TranslateCoordinates(BeamEndWCS, acWorld, acUCS, False)

End With

BeamLenght = Sqr(((BeamEndBCS(0) - BeamStartBCS(0)) ^ 2) + ((BeamEndBCS(1) - BeamStartBCS(1)) ^ 2) + ((BeamEndBCS(2) - BeamStartBCS(2)) ^ 2))

If Abs(BeamStartBCS(0) - BeamEndBCS(0)) < 1000 Then
    ThisDrawing.SendCommand "_box" & vbCr & BeamStartBCS(0) & "," & BeamStartBCS(1) & "," & BeamStartBCS(2) & vbCr & "_l" & vbCr & X & vbCr & BeamLenght & vbCr & "-" & Y & vbCr
End If

If Abs(BeamStartBCS(1) - BeamEndBCS(1)) < 1000 Then
    ThisDrawing.SendCommand "_box" & vbCr & BeamStartBCS(0) & "," & BeamStartBCS(1) & "," & BeamStartBCS(2) & vbCr & "_l" & vbCr & BeamLenght & vbCr & X & vbCr & "-" & Y & vbCr
End If

Main_Controls.Show
```

End Sub

Private Sub ComboBox2_Change()

Dim H As Double

Dim ColumnLenght As Variant

Select Case ComboBox2.Text

Case "h = 270 mm"
H = 270

Case "h = 300 mm"
H = 300

Case "h = 350 mm"
H = 350

Case "h = 370 mm"
H = 370

Case "h = 400 mm"
H = 400

End Select

"MsgBox H

Dim Building3D As AcadView

Dim ActVport As AcadViewport

Dim ActUCS As AcadUCS

ThisDrawing.ActiveSpace = acModelSpace

Set Building3D = ThisDrawing.Views.Item(2)

Set ActVport = ThisDrawing.ActiveViewport

Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)

ActVport.SetView Building3D

ThisDrawing.ActiveViewport = ActVport

ThisDrawing.ActiveUCS = ActUCS

Dim BeamStartWCS As Variant

Dim BeamStartBCS As Variant

Dim BeamHeight As Variant

```
Dim BeamHeight1WCS As Variant
Dim BeamHeight1BCS As Variant
```

```
"Dim BeamHeight2 As Variant
Dim BeamLenght As Double
Dim BeamWidth1WCS As Variant
```

```
Dim BeamWidth As Variant
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
```

```
    BeamStartWCS = .GetPoint(, vbCr & "Pick the Beam Start Point: ")
    BeamStartBCS = .TranslateCoordinates(BeamStartWCS, acWorld, acUCS,
False)
    BeamLenght = .GetDistance(BeamStartBCS, vbCr & "Specify the X direction
lenght of the beam: ")
    BeamWidth = .GetDistance(BeamStartBCS, vbCr & "Specify the Y direction
lenght of the beam: ")
End With
```

```
ThisDrawing.SendCommand "_box" & vbCr & BeamStartBCS(0) & "," &
BeamStartBCS(1) & "," & BeamStartBCS(2) & vbCr & "_l" & vbCr & BeamLenght &
vbCr & BeamWidth & vbCr & "-" & H & vbCr
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub ComboBox3_Change()
```

```
Dim H As Double
```

```
    Select Case ComboBox3.Text
```

```
        Case "h = 80 mm"
            H = 80
```

```
        Case "h = 100 mm"
            H = 100
```

```
        Case "h = 120 mm"
            H = 120
```

```
        Case "h = 150 mm"
            H = 150
```

```
Case "h = 200 mm"
H = 200

End Select

"MsgBox "H= " & H

Dim Building3D As AcadView
Dim ActVport As AcadViewport
Dim ActUCS As AcadUCS
    ThisDrawing.ActiveSpace = acModelSpace
    Set Building3D = ThisDrawing.Views.Item(2)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
    ActVport.SetView Building3D
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS

"Dim Region As AcadEntity
"Dim Rectangle As AcadEntity

Dim FirstPointBCS As Variant
Dim FirstPointWCS As Variant

Dim SecondPointBCS As Variant
Dim SecondPointWCS As Variant

Dim RegionArray As Variant

Main_Controls.Hide

With ThisDrawing.Utility

FirstPointWCS = .GetPoint(, vbCr & "Pick the Start Point: ")
FirstPointBCS = .TranslateCoordinates(FirstPointWCS, acWorld, acUCS, False)

SecondPointWCS = .GetPoint(, vbCr & "Pick the End Point: ")
SecondPointBCS = .TranslateCoordinates(SecondPointWCS, acWorld, acUCS, False)

"MsgBox FirstPointBCS(0) & vbCr & SecondPointBCS(0)

ThisDrawing.SendCommand "_box" & vbCr & FirstPointBCS(0) & "," &
FirstPointBCS(1) & "," & FirstPointBCS(2) & vbCr & SecondPointBCS(0) & "," &
SecondPointBCS(1) & "," & SecondPointBCS(2) & vbCr & "-" & H & vbCr

Main_Controls.Show
```

End With

End Sub

Private Sub ComboBox4_Change()

Dim H As Double

 Select Case ComboBox4.Text

 Case "h = 200 mm"
 H = 200

 Case "h = 230 mm"
 H = 230

 Case "h = 250 mm"
 H = 250

 Case "h = 270 mm"
 H = 270

 Case "h = 300 mm"
 H = 300

 Case "h = 330 mm"
 H = 330

 End Select

MsgBox "H= " & H

End Sub

Private Sub ComboBox5_Change()

Dim X As Double

Dim Y As Double

 Select Case ComboBox5.Text

 Case "200/600 mm"
 X = 200
 Y = 600

 Case "200/800 mm"

X = 200

Y = 800

Case "200/1000 mm"

X = 200

Y = 1000

Case "250/300 mm"

X = 250

Y = 300

Case "250/400 mm"

X = 250

Y = 400

Case "250/500 mm"

X = 250

Y = 500

Case "250/600 mm"

X = 250

Y = 600

Case "250/700 mm"

X = 250

Y = 700

Case "250/800 mm"

X = 250

Y = 800

Case "250/1000 mm"

X = 250

Y = 1000

Case "300/300 mm"

X = 300

Y = 300

Case "300/400 mm"

X = 300

Y = 400

Case "300/500 mm"

X = 300

Y = 500

Case "300/600 mm"

X = 300

Y = 600

Case "300/700 mm"

X = 300

Y = 700

Case "300/800 mm"

X = 300

Y = 800

Case "400/400 mm"

X = 400

Y = 400

Case "400/500 mm"

X = 400

Y = 500

Case "400/600 mm"

X = 400

Y = 600

End Select

Main_Controls.Hide

"Set the ucs and vport

Dim Building3D As AcadView

Dim ActVport As AcadViewport

Dim ActUCS As AcadUCS

 ThisDrawing.ActiveSpace = acModelSpace

 Set Building3D = ThisDrawing.Views.Item(2)

 Set ActVport = ThisDrawing.ActiveViewport

 Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)

 ActVport.SetView Building3D

 ThisDrawing.ActiveViewport = ActVport

 ThisDrawing.ActiveUCS = ActUCS

Dim ColumnStartWCS As Variant

Dim ColumnStartBCS As Variant

"Dim BeamEndWCS As Variant

"Dim BeamEndBCS As Variant

Dim ColumnHeight As Double

With ThisDrawing.Utility

```
ColumnStartWCS = .GetPoint(, vbCr & "Pick the Column Start Point: ")
ColumnStartBCS = .TranslateCoordinates(ColumnStartWCS, acWorld, acUCS, False)
ColumnHeight = .GetDistance(ColumnStartBCS, vbCr & "Enter the Height of the
column: ")
```

End With

```
ThisDrawing.SendCommand "_box" & vbCr & ColumnStartBCS(0) & "," &
ColumnStartBCS(1) & "," & ColumnStartBCS(2) & vbCr & "_l" & vbCr & X & vbCr
& Y & vbCr & ColumnHeight & vbCr
```

Main_Controls.Show

End Sub

Private Sub ComboBox7_Change()

Dim W As Double

 Select Case ComboBox7.Text

 Case "w = 85 mm"
 W = 85

 Case "w = 135 mm"
 W = 135

 Case "w = 190 mm"
 W = 190

 End Select

"Set the ucs and viewport

Dim Building3D As AcadView

Dim ActVport As AcadViewport

Dim ActUCS As AcadUCS

 ThisDrawing.ActiveSpace = acModelSpace

 Set Building3D = ThisDrawing.Views.Item(2)

 Set ActVport = ThisDrawing.ActiveViewport

 Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)

 ActVport.SetView Building3D

 ThisDrawing.ActiveViewport = ActVport

 ThisDrawing.ActiveUCS = ActUCS

```
Dim FirstPointBCS As Variant  
Dim FirstPointWCS As Variant
```

```
Dim SecondPointBCS As Variant  
Dim SecondPointWCS As Variant
```

```
Dim RegionArray As Variant
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
```

```
FirstPointWCS = .GetPoint(, vbCr & "Pick the Start Point: ")  
FirstPointBCS = .TranslateCoordinates(FirstPointWCS, acWorld, acUCS, False)
```

```
SecondPointWCS = .GetPoint(, vbCr & "Pick the End Point: ")  
SecondPointBCS = .TranslateCoordinates(SecondPointWCS, acWorld, acUCS, False)
```

```
"MsgBox FirstPointBCS(0) & vbCr & SecondPointBCS(0)  
End With
```

```
If Abs(FirstPointBCS(0) - SecondPointBCS(0)) < 200 Then  
ThisDrawing.SendCommand "_box" & vbCr & FirstPointBCS(0) & "," &  
FirstPointBCS(1) & "," & FirstPointBCS(2) & vbCr & (FirstPointBCS(0) + W) & "," &  
SecondPointBCS(1) & "," & FirstPointBCS(2) & vbCr & (SecondPointBCS(2) -  
FirstPointBCS(2)) & vbCr  
End If
```

```
If Abs(FirstPointBCS(1) - SecondPointBCS(1)) < 200 Then  
ThisDrawing.SendCommand "_box" & vbCr & FirstPointBCS(0) & "," &  
FirstPointBCS(1) & "," & FirstPointBCS(2) & vbCr & SecondPointBCS(0) & "," &  
(SecondPointBCS(1) + W) & "," & FirstPointBCS(2) & vbCr & (SecondPointBCS(2) -  
FirstPointBCS(2)) & vbCr  
End If
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub CommandButton1_Click()  
    "This Button switches the view and UCS to 3d building view
```

```
Dim Building3D As AcadView
    ThisDrawing.ActiveSpace = acModelSpace
    Set Building3D = ThisDrawing.Views.Item(2)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
    ActVport.SetView Building3D
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS
    "MsgBox Building3D.Name & ActUCS.Name
End Sub
```

```
Private Sub Add_beam_Click()
    "This button adds a RC structural beam
```

```
Dim Building3D As AcadView
Dim ActVport As AcadViewport
Dim ActUCS As AcadUCS
    ThisDrawing.ActiveSpace = acModelSpace
    Set Building3D = ThisDrawing.Views.Item(2)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
    ActVport.SetView Building3D
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS
```

```
Dim BeamStartWCS As Variant
Dim BeamStartBCS As Variant
```

```
Dim BeamEnd As Variant
Dim BeamHeight As Variant
```

```
Dim BeamHeight1WCS As Variant
Dim BeamHeight1BCS As Variant
```

```
"Dim BeamHeight2 As Variant
Dim BeamLenght As Double
Dim BeamWidth1WCS As Variant
```

```
Dim BeamWidth As Variant
```

```
Main_Controls.Hide
```

```
    With ThisDrawing.Utility
```

```
        BeamStartWCS = .GetPoint(, vbCr & "Pick the Beam Start Point: ")
```

```
BeamStartBCS = .TranslateCoordinates(BeamStartWCS, acWorld, acUCS,  
False)
```

```
BeamLenght = .GetDistance(BeamStartBCS, vbCr & "Specify the X direction  
lenght of the beam: ")
```

```
BeamHeight = .GetDistance(, vbCr & "Specify the beam height: ")  
BeamWidth = .GetDistance(BeamStartBCS, vbCr & "Specify the Y direction  
lenght of the beam: ")  
End With
```

```
ThisDrawing.SendCommand "_box" & vbCr & BeamStartBCS(0) & "," &  
BeamStartBCS(1) & "," & BeamStartBCS(2) & vbCr & "_l" & vbCr & BeamLenght &  
vbCr & BeamWidth & vbCr & "-" & BeamHeight & vbCr
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub CommandButton10_Click()  
"This button cuts solids with a horizontal plane
```

```
Dim Building3D As AcadView  
Dim ActVport As AcadViewport  
Dim ActUCS As AcadUCS  
ThisDrawing.ActiveSpace = acModelSpace  
Set Building3D = ThisDrawing.Views.Item(2)  
Set ActVport = ThisDrawing.ActiveViewport  
Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)  
ActVport.SetView Building3D  
ThisDrawing.ActiveViewport = ActVport  
ThisDrawing.ActiveUCS = ActUCS
```

```
Dim SolidToCut As Acad3DSolid  
Dim NewSolid As Acad3DSolid  
Dim VarPick As Variant  
Dim Pt1 As Variant  
Dim Pt2(2) As Double  
Dim Pt3(2) As Double  
Dim Pt1W As Variant  
Dim Pt2W As Variant  
Dim Pt3W As Variant
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
```

```
.GetEntity SolidToCut, VarPick, vbCr & "Pick the building Component To Cut:"
    "If Err Then
        " MsgBox "That is not a Suitable object"
        "Exit Sub
    "End If
.InitializeUserInput 1
Pt1W = .GetPoint(VarPick, vbCr & "Select a point on slicing plane: ")
Pt1 = .TranslateCoordinates(Pt1W, acWorld, acUCS, False)

Pt2(0) = Pt1(0) + 100
Pt2(1) = Pt1(1)
Pt2(2) = Pt1(2)

Pt3(0) = Pt1(0)
Pt3(1) = Pt1(1) + 100
Pt3(2) = Pt1(2)

Pt2W = .TranslateCoordinates(Pt2, acUCS, acWorld, False)
Pt3W = .TranslateCoordinates(Pt3, acUCS, acWorld, False)

"ThisDrawing.StartUndoMark

Set NewSolid = SolidToCut.SliceSolid(Pt1W, Pt2W, Pt3W, True)
"NewSolid.Update

End With

ThisDrawing.Regen acActiveViewport

Main_Controls.Show

End Sub

Private Sub CommandButton11_Click()
    "This button sends the selected beam data to Excel cells

    Dim Beam As Acad3DSolid
    Dim BeamVol As Variant
    Dim VarPick As Variant
    Dim BeamName As String
    Dim BeamMaterial As String

    Main_Controls.Hide

    With ThisDrawing.Utility
        .GetEntity Beam, VarPick, vbCr & "Pick The Beam to export"
```

```
"If Err Then
    MsgBox "That is not a suitable building component"
    Exit Sub
"End If
End With

BeamVol = Beam.Volume

With ThisDrawing.Utility
    BeamName = .GetString(True, vbCr & "Enter The Name of the Beam: ")
    BeamMaterial = .GetString(True, vbCr & "Enter The Type of Concrete Used (C20/
C30 etc.): ")
End With

    RowNo = RowNo + 1

    "Write Item Name
    FirstWorksheet.Cells(RowNo, ColNo).Value = BeamName

    "Write the Material
    FirstWorksheet.Cells(RowNo, ColNo + 1).Value = BeamMaterial

    "Write The Quantity of Volume
    FirstWorksheet.Cells(RowNo, ColNo + 4).Value = BeamVol / 1000000000

    "Write The Unite Price
    FirstWorksheet.Cells(RowNo, ColNo + 3).Value = 10

    "Write The cost of the building component
    FirstWorksheet.Cells(RowNo, ColNo + 5).Value = BeamVol / 100000000

    NewWorkbook.Save

Beam.Layer = "Concrete"
Beam.Update

Main_Controls.Show

End Sub

Private Sub CommandButton12_Click()
    "This button sends the selected Column data to Excel cells

    Dim Column As Acad3DSolid
    Dim ColumnVol As Variant
    Dim VarPick As Variant
```

```
Dim ColumnName As String
Dim ColumnMaterial As String
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
    .GetEntity Column, VarPick, vbCr & "Pick The Column to export"
    "If Err Then
        MsgBox "That is not a suitable building component"
    "Exit Sub
    "End If
End With
```

```
ColumnVol = Column.Volume
```

```
With ThisDrawing.Utility
    ColumnName = .GetString(True, vbCr & "Enter The Name of the Column: ")
    ColumnMaterial = .GetString(True, vbCr & "Enter The Type of Concrete Used
(C20/ C30 etc.): ")
End With
```

```
RowNo = RowNo + 1
```

```
"Write Item Name
FirstWorksheet.Cells(RowNo, ColNo).Value = ColumnName
```

```
"Write the Material
FirstWorksheet.Cells(RowNo, ColNo + 1).Value = ColumnMaterial
```

```
"Write The Quantity of Volume
FirstWorksheet.Cells(RowNo, ColNo + 4).Value = ColumnVol / 1000000000
```

```
"Write The Unite Price
FirstWorksheet.Cells(RowNo, ColNo + 3).Value = 10
```

```
"Write The cost of the building component
FirstWorksheet.Cells(RowNo, ColNo + 5).Value = ColumnVol / 1000000000
```

```
NewWorkbook.Save
```

```
Column.Layer = "Concrete"
Column.Update
```

```
Main_Controls.Show
End Sub
```

```
Private Sub CommandButton13_Click()
    "This button sends the sellected beam data to Excel cells
```



```
Dim Beam As Acad3DSolid
Dim BeamVol As Variant
Dim VarPick As Variant
Dim BeamName As String
Dim BeamMaterial As String
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
    .GetEntity Beam, VarPick, vbCr & "Pick The Beam to export"
    If Err Then
        MsgBox "That is not a suitable building component"
        Exit Sub
    End If
End With
```

```
BeamVol = Beam.Volume
```

```
With ThisDrawing.Utility
    BeamName = .GetString(True, vbCr & "Enter The Name of the Beam: ")
    BeamMaterial = .GetString(True, vbCr & "Enter The Type of Concrete Used (C20/
C30 etc.): ")
End With
```

```
RowNo = RowNo + 1
```

```
"Write Item Name
FirstWorksheet.Cells(RowNo, ColNo).Value = BeamName
```

```
"Write the Material
FirstWorksheet.Cells(RowNo, ColNo + 1).Value = BeamMaterial
```

```
"Write The Quantity of Volume
FirstWorksheet.Cells(RowNo, ColNo + 4).Value = BeamVol / 1000000000
```

```
"Write The Unite Price
FirstWorksheet.Cells(RowNo, ColNo + 3).Value = 10
```

```
"Write The cost of the building component
FirstWorksheet.Cells(RowNo, ColNo + 5).Value = BeamVol / 100000000
```

```
NewWorkbook.Save
```

```
Beam.Layer = "Concrete"
Beam.Update
```

```
Main_Controls.Show
```

End Sub

Private Sub CommandButton14_Click()

 "This button sends the sellected Slab data to Excel cells

 Dim Slab As Acad3DSolid

 Dim SlabVol As Variant

 Dim VarPick As Variant

 Dim SlabName As String

 Dim SlabMaterial As String

 Main_Controls.Hide

 With ThisDrawing.Utility

 .GetEntity Slab, VarPick, vbCr & "Pick The Slab to export"

 "If Err Then

 "MsgBox "That is not a suitable building component"

 "Exit Sub

 "End If

 End With

 SlabVol = Slab.Volume

 With ThisDrawing.Utility

 SlabName = .GetString(True, vbCr & "Enter The Name of the Slab: ")

 SlabMaterial = .GetString(True, vbCr & "Enter The Type of Concrete Used (C20/
C30 etc.): ")

 End With

 RowNo = RowNo + 1

 "Write Item Name

 FirstWorksheet.Cells(RowNo, ColNo).Value = SlabName

 "Write the Material

 FirstWorksheet.Cells(RowNo, ColNo + 1).Value = SlabMaterial

 "Write The Quantity of Volume

 FirstWorksheet.Cells(RowNo, ColNo + 4).Value = SlabVol / 1000000000

 "Write The Unite Price

 FirstWorksheet.Cells(RowNo, ColNo + 3).Value = 10

 "Write The cost of the building component

 FirstWorksheet.Cells(RowNo, ColNo + 5).Value = SlabVol / 100000000

```
NewWorkbook.Save

Slab.Layer = "Concrete"
Slab.Update

Main_Controls.Show
End Sub

Private Sub CommandButton15_Click()
"This button adds a non-structural wall with free thickness

Dim Building3D As AcadView
Dim ActVport As AcadViewport
Dim ActUCS As AcadUCS
    ThisDrawing.ActiveSpace = acModelSpace
    Set Building3D = ThisDrawing.Views.Item(2)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
    ActVport.SetView Building3D
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS

Dim WallStartWCS As Variant
Dim WallStartBCS As Variant

Dim WallEnd As Variant
Dim WallHeight As Variant

Dim WallHeight1WCS As Variant
Dim WallHeight1BCS As Variant

Dim WallLenght As Double
Dim WallWidth1WCS As Variant

Dim WallWidth As Variant

Main_Controls.Hide

With ThisDrawing.Utility

    WallStartWCS = .GetPoint(, vbCr & "Pick the Wall Start Point: ")
    WallStartBCS = .TranslateCoordinates(WallStartWCS, acWorld, acUCS, False)
```

```
WallLenght = .GetDistance(WallStartBCS, vbCr & "Specify the X direction  
lenght of the Wall: ")
```

```
WallHeight = .GetDistance(, vbCr & "Specify the Wall height: ")  
WallWidth = .GetDistance(WallStartBCS, vbCr & "Specify the Y direction  
lenght of the Wall: ")  
End With
```

```
ThisDrawing.SendCommand "_box" & vbCr & WallStartBCS(0) & "," &  
WallStartBCS(1) & "," & WallStartBCS(2) & vbCr & "_l" & vbCr & WallLenght &  
vbCr & WallWidth & vbCr & WallHeight & vbCr
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub CommandButton16_Click()  
Dim Wall As Acad3DSolid  
Dim WallVol As Variant  
Dim VarPick As Variant  
Dim WallName As String  
Dim WallMaterial As String
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility  
.GetEntity Wall, VarPick, vbCr & "Pick The Wall to export"  
"If Err Then  
"MsgBox "That is not a suitable building component"  
"Exit Sub  
"End If  
End With
```

```
WallVol = Wall.Volume
```

```
With ThisDrawing.Utility  
WallName = .GetString(True, vbCr & "Enter The Name of the Wall: ")  
"WallMaterial = .GetString(True, vbCr & "Enter The Type of Brick Used (85/ 135  
or 190): ")  
End With
```

```
WallMaterial = "8,5/ 13,5 or 19 cm Red Blocks"
```

```
RowNo = RowNo + 1
```

```
"Write Item Name  
FirstWorksheet.Cells(RowNo, ColNo).Value = WallName
```

```
"Write the Material
FirstWorksheet.Cells(RowNo, ColNo + 1).Value = WallMaterial

"Write The Quantity of Volume
FirstWorksheet.Cells(RowNo, ColNo + 4).Value = WallVol / 1000000000

"Write The Unite Price
FirstWorksheet.Cells(RowNo, ColNo + 3).Value = 5

"Write The cost of the building component
FirstWorksheet.Cells(RowNo, ColNo + 5).Value = WallVol / 1000000000

NewWorkbook.Save

Wall.Layer = "RedBrick"
Wall.Update

Main_Controls.Show
End Sub

Private Sub CommandButton2_Click()
    "This button switches the view to the image, and the UCS to the world
    ThisDrawing.ActiveSpace = acModelSpace
    Set ImageView = ThisDrawing.Views.Item(1)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(1)
    ActVport.SetView ImageView
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS
    "MsgBox ImageView.Name & ActUCS.Name
End Sub

Private Sub CommandButton3_Click()
    "This button renders the model so that the progress can be previewed
Dim Preview As AcadView
    ThisDrawing.ActiveSpace = acModelSpace
    Set Preview = ThisDrawing.Views.Item(0)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(1)
    ActVport.SetView Preview
    ThisDrawing.ActiveViewport = ActVport
    "MsgBox Preview.Name & ActUCS.Name
Main_Controls.Hide
ThisDrawing.SendCommand "_Render" & vbCr
Main_Controls.Show
End Sub
```

```
Private Sub CommandButton9_Click()
```

```
End Sub
```

```
Private Sub Copy_Click()
```

```
    "This button copies items
```

```
Dim FromPoint As Variant
```

```
Dim ToPoint As Variant
```

```
Dim objSelectionSetToCopy As AcadSelectionSet
```

```
Dim ObjectstoCopy As AcadEntity
```

```
Dim CopiedObject As AcadEntity
```

```
On Error Resume Next
```

```
ThisDrawing.SelectionSets("TempSSet").Delete
```

```
Set objSelectionSetToCopy = ThisDrawing.SelectionSets.Add("TempSSet")
```

```
Main_Controls.Hide
```

```
objSelectionSetToCopy.SelectOnScreen
```

```
FromPoint = ThisDrawing.Utility.GetPoint(, vbCrLf & "Base point of displacement: ")
```

```
ToPoint = ThisDrawing.Utility.GetPoint(FromPoint, vbCrLf & "Second point of  
displacement: ")
```

```
For Each ObjectstoCopy In objSelectionSetToCopy
```

```
    Set CopiedObject = ObjectstoCopy.Copy()
```

```
    CopiedObject.Move FromPoint, ToPoint
```

```
    ObjectstoCopy.Update
```

```
Next
```

```
objSelectionSetToCopy.Delete
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub Cut_Vertically_y_Click()
```

```
"This button cuts solids with a vertical plane
```

```
Dim Building3D As AcadView
```

```
Dim ActVport As AcadViewport
```

```
Dim ActUCS As AcadUCS
```

```
    ThisDrawing.ActiveSpace = acModelSpace
```

```
    Set Building3D = ThisDrawing.Views.Item(2)
```

```
    Set ActVport = ThisDrawing.ActiveViewport
```

```
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
```

```
    ActVport.SetView Building3D
```

```
ThisDrawing.ActiveViewport = ActVport  
ThisDrawing.ActiveUCS = ActUCS
```

```
Dim SolidToCut As Acad3DSolid  
Dim NewSolid As Acad3DSolid  
Dim VarPick As Variant  
Dim Pt1 As Variant  
Dim Pt2(2) As Double  
Dim Pt3(2) As Double  
Dim Pt1W As Variant  
Dim Pt2W As Variant  
Dim Pt3W As Variant
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
```

```
    .GetEntity SolidToCut, VarPick, vbCr & "Pick the building Component To Cut:"
```

```
    If Err Then
```

```
        MsgBox "That is not a Suitable object"
```

```
        Exit Sub
```

```
    End If
```

```
    .InitializeUserInput 1
```

```
    Pt1W = .GetPoint(VarPick, vbCr & "Select a point on slicing plane: ")
```

```
    Pt1 = .TranslateCoordinates(Pt1W, acWorld, acUCS, False)
```

```
    Pt2(0) = Pt1(0)
```

```
    Pt2(1) = Pt1(1) + 100
```

```
    Pt2(2) = Pt1(2)
```

```
    Pt3(0) = Pt1(0)
```

```
    Pt3(1) = Pt1(1)
```

```
    Pt3(2) = Pt1(2) + 100
```

```
    Pt2W = .TranslateCoordinates(Pt2, acUCS, acWorld, False)
```

```
    Pt3W = .TranslateCoordinates(Pt3, acUCS, acWorld, False)
```

```
    "ThisDrawing.StartUndoMark
```

```
    Set NewSolid = SolidToCut.SliceSolid(Pt1W, Pt2W, Pt3W, True)
```

```
    "NewSolid.Update
```

```
End With
```

```
ThisDrawing.Regen acActiveViewport
```

```
Main_Controls.Show
```

End Sub

Private Sub Frame2_Click()

End Sub

Private Sub Frame3_Click()

End Sub

Private Sub Leave_trace_Click()

"This button draws a region object on a selected solid to take measurements

"Change the view and UCS

Dim ImageView As AcadView

Dim ActVport As AcadViewport

Dim ActUCS As AcadUCS

 ThisDrawing.ActiveSpace = acModelSpace

 Set ImageView = ThisDrawing.Views.Item(1)

 Set ActVport = ThisDrawing.ActiveViewport

 Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(1)

 ActVport.SetView ImageView

 ThisDrawing.ActiveViewport = ActVport

 ThisDrawing.ActiveUCS = ActUCS

"Leave the trace

Dim SolidToCut As Acad3DSolid

Dim Region As AcadRegion

Dim VarPick As Variant

Dim FirstPoint As Variant

Dim SecondPoint As Variant

Main_Controls.Hide

With ThisDrawing.Utility

 .GetEntity SolidToCut, VarPick, vbCr & "Pick a Building Component: "

 FirstPoint = .GetPoint(, vbCr & "Enter the First point to specify the edge: ")

 SecondPoint = .GetPoint(, vbCr & "Enter the Second point to specify the edge: ")

End With

Set Region = SolidToCut.SectionSolid(PeakPoint, FirstPoint, SecondPoint)

"MsgBox PeakPoint(0) & vbCr & PeakPoint(1) & vbCr & PeakPoint(2)

Main_Controls.Show

End Sub

Private Sub Measure_Distance_Click()

 "Abs distance between 2 points

Dim Building3D As AcadView

Dim ActVport As AcadViewport

Dim ActUCS As AcadUCS

 ThisDrawing.ActiveSpace = acModelSpace

 Set Building3D = ThisDrawing.Views.Item(2)

 Set ActVport = ThisDrawing.ActiveViewport

 Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)

 ActVport.SetView Building3D

 ThisDrawing.ActiveViewport = ActVport

 ThisDrawing.ActiveUCS = ActUCS

Dim StartWCS As Variant

Dim StartBCS As Variant

Dim EndWCS As Variant

Dim EndBCS As Variant

Dim Lenght As Double

Dim DX As Double

Dim DY As Double

Dim DZ As Double

Main_Controls.Hide

With ThisDrawing.Utility

StartWCS = .GetPoint(, vbCr & "Pick the Start Point: ")

StartBCS = .TranslateCoordinates(StartWCS, acWorld, acUCS, False)

EndWCS = .GetPoint(, vbCr & "Pick the End Point: ")

EndBCS = .TranslateCoordinates(EndWCS, acWorld, acUCS, False)

End With

Lenght = Sqr(((EndBCS(0) - StartBCS(0)) ^ 2) + ((EndBCS(1) - StartBCS(1)) ^ 2) +
((EndBCS(2) - StartBCS(2)) ^ 2))

DX = EndBCS(0) - StartBCS(0)

DY = EndBCS(1) - StartBCS(1)

DZ = EndBCS(2) - StartBCS(2)

```
MsgBox "Absolute Value of Distance: " & vbCrLf & Lenght & "mm" & vbCrLf & "DX: " & DX & "mm" & vbCrLf & "DY: " & DY & "mm" & vbCrLf & "DZ: " & DZ & "mm"
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub Move_Click()
```

```
    "This button moves objects around
```

```
    Dim FromPoint As Variant
```

```
    Dim ToPoint As Variant
```

```
    Dim objSelectionSetToMove As AcadSelectionSet
```

```
    Dim ObjectstoMove As AcadEntity
```

```
On Error Resume Next
```

```
ThisDrawing.SelectionSets("TempSSet").Delete
```

```
Set objSelectionSetToMove = ThisDrawing.SelectionSets.Add("TempSSet")
```

```
Main_Controls.Hide
```

```
objSelectionSetToMove.SelectOnScreen
```

```
FromPoint = ThisDrawing.Utility.GetPoint(, vbCrLf & "Base point of displacement: ")
```

```
ToPoint = ThisDrawing.Utility.GetPoint(FromPoint, vbCrLf & "Second point of displacement: ")
```

```
For Each ObjectstoMove In objSelectionSetToMove
```

```
    ObjectstoMove.Move FromPoint, ToPoint
```

```
    ObjectstoMove.Update
```

```
Next
```

```
objSelectionSetToMove.Delete
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub MultiPage1_Change()
```

```
End Sub
```

```
Private Sub Rectangular_Column_Click()
```

```
    "this button draws a rectangular column
```

```
Dim Building3D As AcadView
```

```
Dim ActVport As AcadViewport
```

```
Dim ActUCS As AcadUCS
```

```
    ThisDrawing.ActiveSpace = acModelSpace
```

```
    Set Building3D = ThisDrawing.Views.Item(2)
```

```
    Set ActVport = ThisDrawing.ActiveViewport
```

```
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
```

```
    ActVport.SetView Building3D
```

```
    ThisDrawing.ActiveViewport = ActVport
```

```
    ThisDrawing.ActiveUCS = ActUCS
```

```
Dim columnWidth As Double
```

```
Dim columnDepth As Double
```

```
Dim ColumnHeight As Double
```

```
Dim columnFirstCornerWCS As Variant
```

```
Dim columnFirstCornerBCS As Variant
```

```
Dim buildingUCS As AcadUCS
```

```
Dim worldUCS As AcadUCS
```

```
Main_Controls.Hide
```

```
    With ThisDrawing.Utility
```

```
        columnFirstCornerWCS = .GetPoint(, vbCr & "Enter the 1st known corner of the  
column: ")
```

```
        columnFirstCornerBCS = .TranslateCoordinates(columnFirstCornerWCS,  
acWorld, acUCS, False)
```

```
        columnDepth = .GetDistance(columnFirstCornerBCS, vbCr & "Enter the Depth of  
the column: ")
```

```
        columnWidth = .GetDistance(columnFirstCornerBCS, vbCr & "Enter the width of  
the column: ")
```

```
        ColumnHeight = .GetDistance(columnFirstCornerBCS, vbCr & "Enter the Height  
of the column: ")
```

```
    End With
```

```
ThisDrawing.SendCommand "_box" & vbCr & columnFirstCornerBCS(0) & "," &  
columnFirstCornerBCS(1) & "," & columnFirstCornerBCS(2) & vbCr & "_1" & vbCr &  
columnDepth & vbCr & columnWidth & vbCr & ColumnHeight & vbCr
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub CommandButton6_Click()
```

```
    "This Button erases objects
```

```
Dim objSS As AcadSelectionSet
```

Main_Controls.Hide

With ThisDrawing.Utility

```
Set objSS = ThisDrawing.SelectionSets.Add("select things to erase2")
objSS.SelectOnScreen
objSS.Highlight True
objSS.Erase
objSS.Delete
```

End With

ThisDrawing.Regen acActiveViewport

Main_Controls.Show

End Sub

Private Sub Cut_Horizontally_Click()
"This button cuts solids with a horizontal plane

```
Dim Building3D As AcadView
Dim ActVport As AcadViewport
Dim ActUCS As AcadUCS
ThisDrawing.ActiveSpace = acModelSpace
Set Building3D = ThisDrawing.Views.Item(2)
Set ActVport = ThisDrawing.ActiveViewport
Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
ActVport.SetView Building3D
ThisDrawing.ActiveViewport = ActVport
ThisDrawing.ActiveUCS = ActUCS
```

```
Dim SolidToCut As Acad3DSolid
Dim NewSolid As Acad3DSolid
Dim VarPick As Variant
Dim Pt1 As Variant
Dim Pt2(2) As Double
Dim Pt3(2) As Double
Dim Pt1W As Variant
Dim Pt2W As Variant
Dim Pt3W As Variant
```

Main_Controls.Hide

With ThisDrawing.Utility

```
.GetEntity SolidToCut, VarPick, vbCr & "Pick the building Component To Cut:"
```

```
If Err Then
    MsgBox "That is not a Suitable object"
Exit Sub
End If
.InitializeUserInput 1
Pt1W = .GetPoint(VarPick, vbCr & "Select a point on slicing plane: ")
Pt1 = .TranslateCoordinates(Pt1W, acWorld, acUCS, False)

Pt2(0) = Pt1(0) + 100
Pt2(1) = Pt1(1)
Pt2(2) = Pt1(2)

Pt3(0) = Pt1(0)
Pt3(1) = Pt1(1) + 100
Pt3(2) = Pt1(2)

Pt2W = .TranslateCoordinates(Pt2, acUCS, acWorld, False)
Pt3W = .TranslateCoordinates(Pt3, acUCS, acWorld, False)

"ThisDrawing.StartUndoMark

Set NewSolid = SolidToCut.SliceSolid(Pt1W, Pt2W, Pt3W, True)
"NewSolid.Update

End With

ThisDrawing.Regen acActiveViewport

Main_Controls.Show

End Sub

Private Sub Cut_Vertically_x_Click()
"This button cuts solids with a vertical plane

Dim Building3D As AcadView
Dim ActVport As AcadViewport
Dim ActUCS As AcadUCS
    ThisDrawing.ActiveSpace = acModelSpace
    Set Building3D = ThisDrawing.Views.Item(2)
    Set ActVport = ThisDrawing.ActiveViewport
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(0)
    ActVport.SetView Building3D
    ThisDrawing.ActiveViewport = ActVport
    ThisDrawing.ActiveUCS = ActUCS
```

```
Dim SolidToCut As Acad3DSolid
Dim NewSolid As Acad3DSolid
Dim VarPick As Variant
Dim Pt1 As Variant
Dim Pt2(2) As Double
Dim Pt3(2) As Double
Dim Pt1W As Variant
Dim Pt2W As Variant
Dim Pt3W As Variant

Main_Controls.Hide

With ThisDrawing.Utility
    .GetEntity SolidToCut, VarPick, vbCr & "Pick the building Component To Cut:"
    "If Err Then
        MsgBox "That is not a Suitable object"
    "Exit Sub
    "End If
    .InitializeUserInput 1
    Pt1W = .GetPoint(VarPick, vbCr & "Select a point on slicing plane: ")
    Pt1 = .TranslateCoordinates(Pt1W, acWorld, acUCS, False)

    Pt2(0) = Pt1(0) + 100
    Pt2(1) = Pt1(1)
    Pt2(2) = Pt1(2)

    Pt3(0) = Pt1(0)
    Pt3(1) = Pt1(1)
    Pt3(2) = Pt1(2) + 100

    Pt2W = .TranslateCoordinates(Pt2, acUCS, acWorld, False)
    Pt3W = .TranslateCoordinates(Pt3, acUCS, acWorld, False)

    "ThisDrawing.StartUndoMark
    Set NewSolid = SolidToCut.SliceSolid(Pt1W, Pt2W, Pt3W, True)
    "NewSolid.Update

End With

ThisDrawing.Regen acActiveViewport

Main_Controls.Show

End Sub
```

```
Private Sub Rotate3D_Click()  
    "This button rotates objects around a coordinate  
    Dim EntityPickedPoint As Variant  
    Dim ObjectToRotate As AcadEntity  
    Dim AxisPoint1 As Variant  
    Dim AxisPoint2 As Variant  
    Dim RotationAngle As Double  
  
    Main_Controls.Hide  
    On Error Resume Next  
    ThisDrawing.Utility.GetEntity ObjectToRotate, EntityPickedPoint, "Please select an  
    entity to rotate: "  
  
    AxisPoint1 = ThisDrawing.Utility.GetPoint(, "Enter first point of axis of rotation: ")  
    AxisPoint2 = ThisDrawing.Utility.GetPoint(, "Enter second point of axis of rotation: ")  
    RotationAngle = ThisDrawing.Utility.GetReal("Enter angle of rotation in degrees: ")  
    RotationAngle = ThisDrawing.Utility.AngleToReal(CStr(RotationAngle), acDegrees)  
  
    ObjectToRotate.Rotate3D AxisPoint1, AxisPoint2, RotationAngle  
    ObjectToRotate.Update  
  
    Main_Controls.Show  
  
End Sub
```

```
Private Sub Subtract_Intersection_Click()  
  
    Dim ObjectToSubtractFrom As Acad3DSolid  
    Dim ObjectToSubtract As Acad3DSolid  
    Dim CopyObjectToSubtract As Acad3DSolid  
    "Dim NewSolid As Acad3DSolid  
    Dim PickPoint1 As Variant  
    Dim PickPoint2 As Variant  
  
    Main_Controls.Hide  
  
    With ThisDrawing.Utility  
        .GetEntity ObjectToSubtractFrom, PickPoint1, vbCr & "Pick the solid to subtract  
        from: "  
        .GetEntity ObjectToSubtract, PickPoint2, vbCr & "Pick the solid to subtract: "  
    End With  
    Set CopyObjectToSubtract = ObjectToSubtract.Copy()  
    ObjectToSubtractFrom.Boolean acSubtraction, CopyObjectToSubtract
```

```
ThisDrawing.SendCommand "regen" & vbCr
```

```
Main_Controls.Show
```

```
End Sub
```

```
Private Sub Take_Measurement_Click()
```

```
"This button draws a region object on a selected solid to take measurements
```

```
"Change the view and UCS
```

```
Dim ImageView As AcadView
```

```
Dim ActVport As AcadViewport
```

```
Dim ActUCS As AcadUCS
```

```
    ThisDrawing.ActiveSpace = acModelSpace
```

```
    Set ImageView = ThisDrawing.Views.Item(1)
```

```
    Set ActVport = ThisDrawing.ActiveViewport
```

```
    Set ActUCS = ThisDrawing.UserCoordinateSystems.Item(1)
```

```
    ActVport.SetView ImageView
```

```
    ThisDrawing.ActiveViewport = ActVport
```

```
    ThisDrawing.ActiveUCS = ActUCS
```

```
"Leave the trace
```

```
Dim SolidToCut As Acad3DSolid
```

```
Dim Region As AcadRegion
```

```
Dim VarPick As Variant
```

```
Dim FirstPoint As Variant
```

```
Dim SecondPoint As Variant
```

```
Main_Controls.Hide
```

```
With ThisDrawing.Utility
```

```
    .GetEntity SolidToCut, VarPick, vbCr & "Pick a Building Component: "
```

```
    FirstPoint = .GetPoint(, vbCr & "Enter the First point to specify the edge: ")
```

```
    SecondPoint = .GetPoint(, vbCr & "Enter the Second point to specify the edge: ")
```

```
End With
```

```
Set Region = SolidToCut.SectionSolid(PeakPoint, FirstPoint, SecondPoint)
```

```
"MsgBox PeakPoint(0) & vbCr & PeakPoint(1) & vbCr & PeakPoint(2)
```

```
Main_Controls.Show
```

```
End Sub
```



```
Private Sub Undo_Click()
```

```
    Main_Controls.Hide
```

```
    Dim UndoNo As Integer
```

```
    With ThisDrawing.Utility
```

```
        UndoNo = .GetInteger(vbCr & "Enter the number of operations to Undo: ")
```

```
    End With
```

```
    ThisDrawing.SendCommand "Undo" & vbCr & UndoNo & vbCr
```

```
    Main_Controls.Show
```

```
End Sub
```

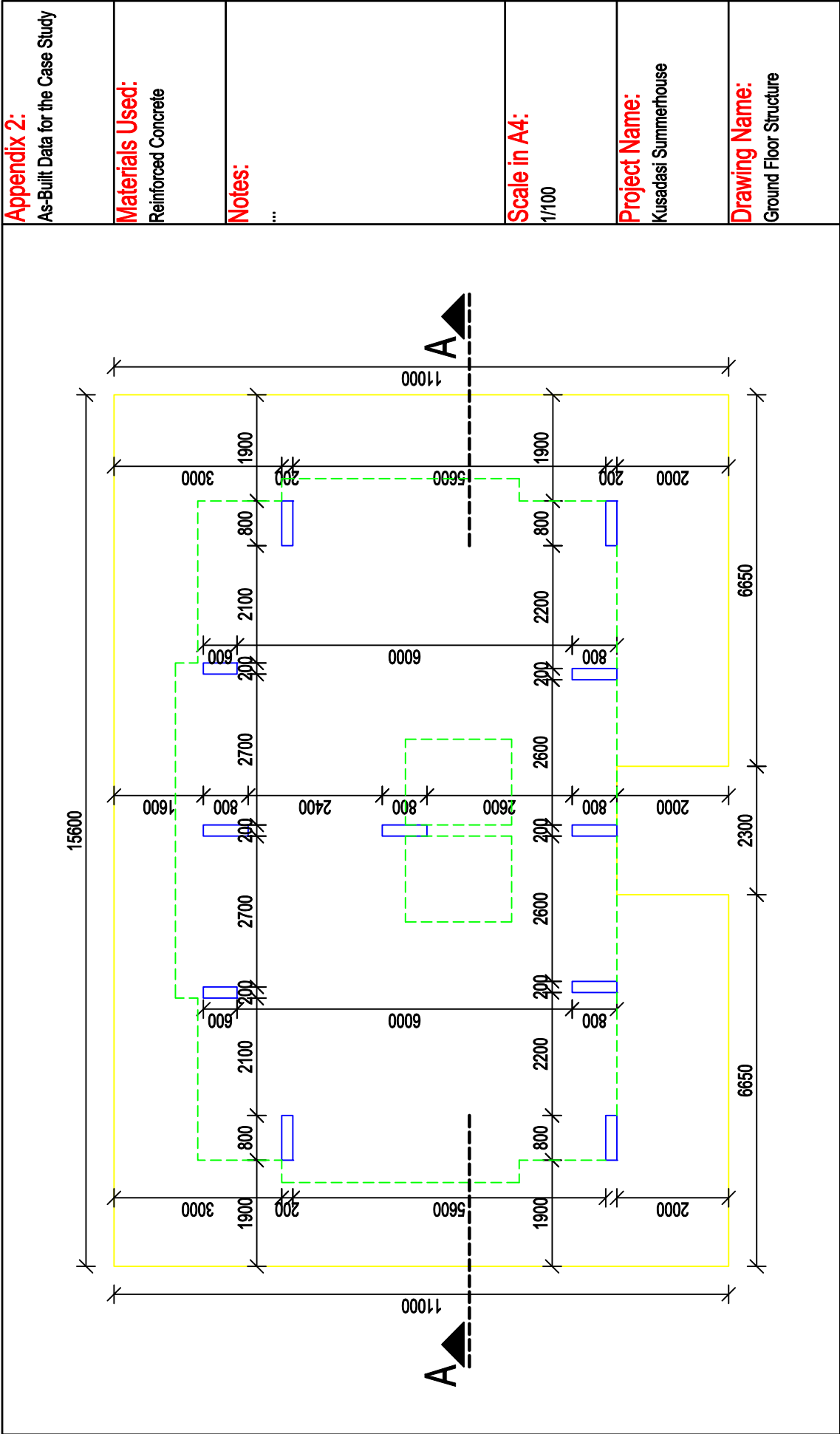
```
Private Sub UserForm_Click()
```

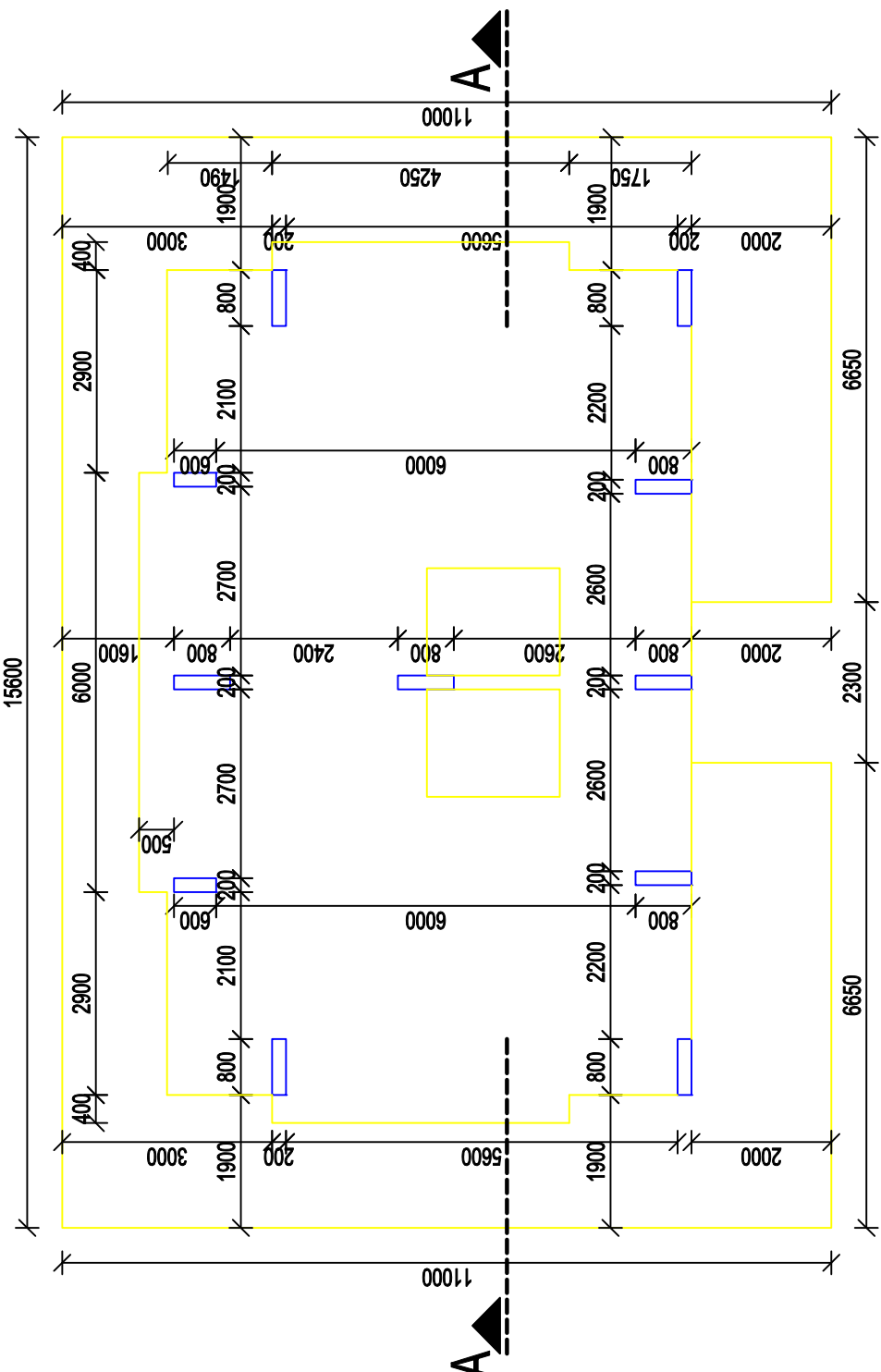
```
End Sub
```

Appendix 2. CAD Drawings	245
---------------------------------------	------------

Appendix 2. CAD Drawings

Following drawings are produced using manual on-site measurement techniques in order to make comparisons with results of the proposed technique.

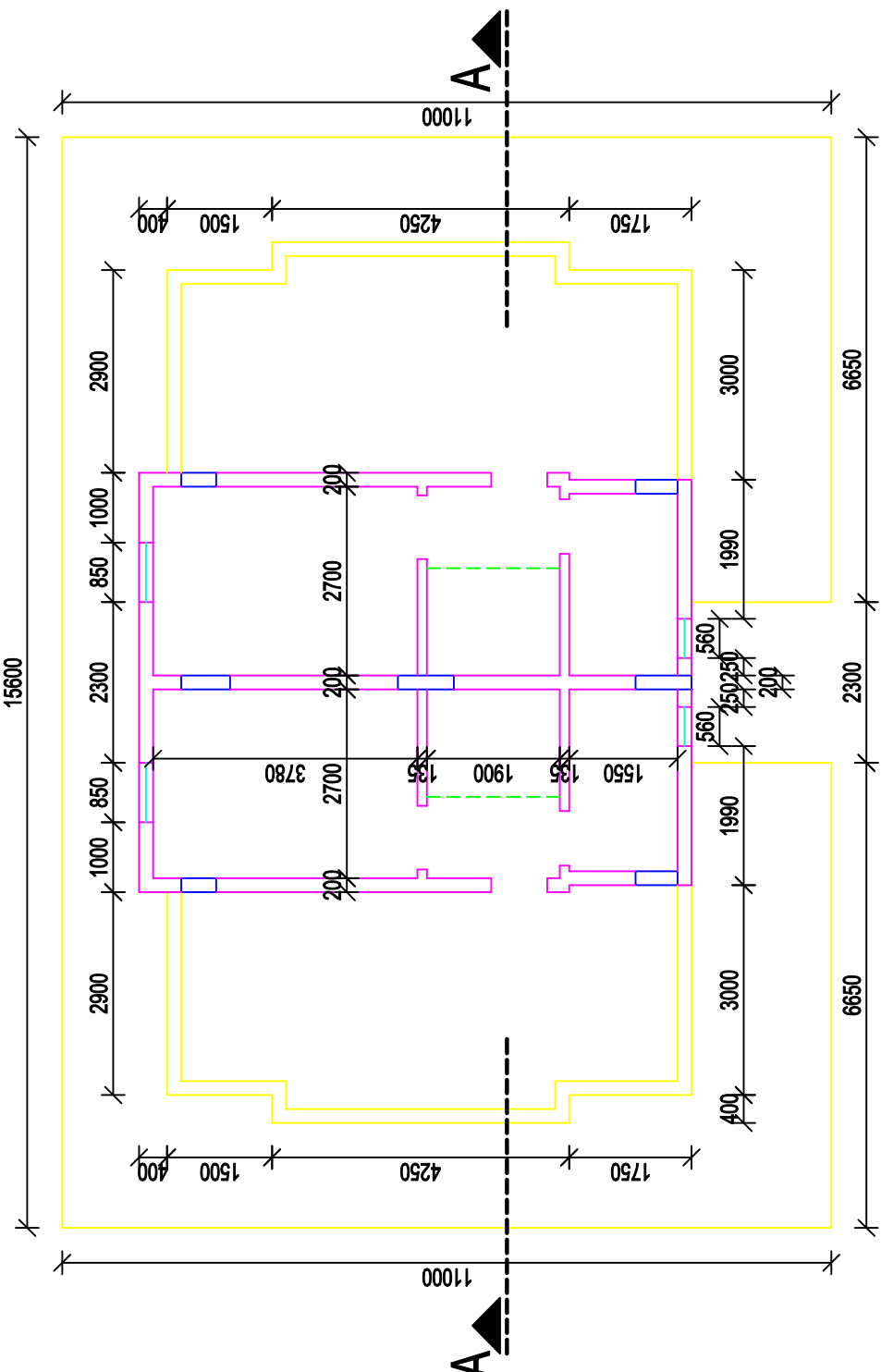


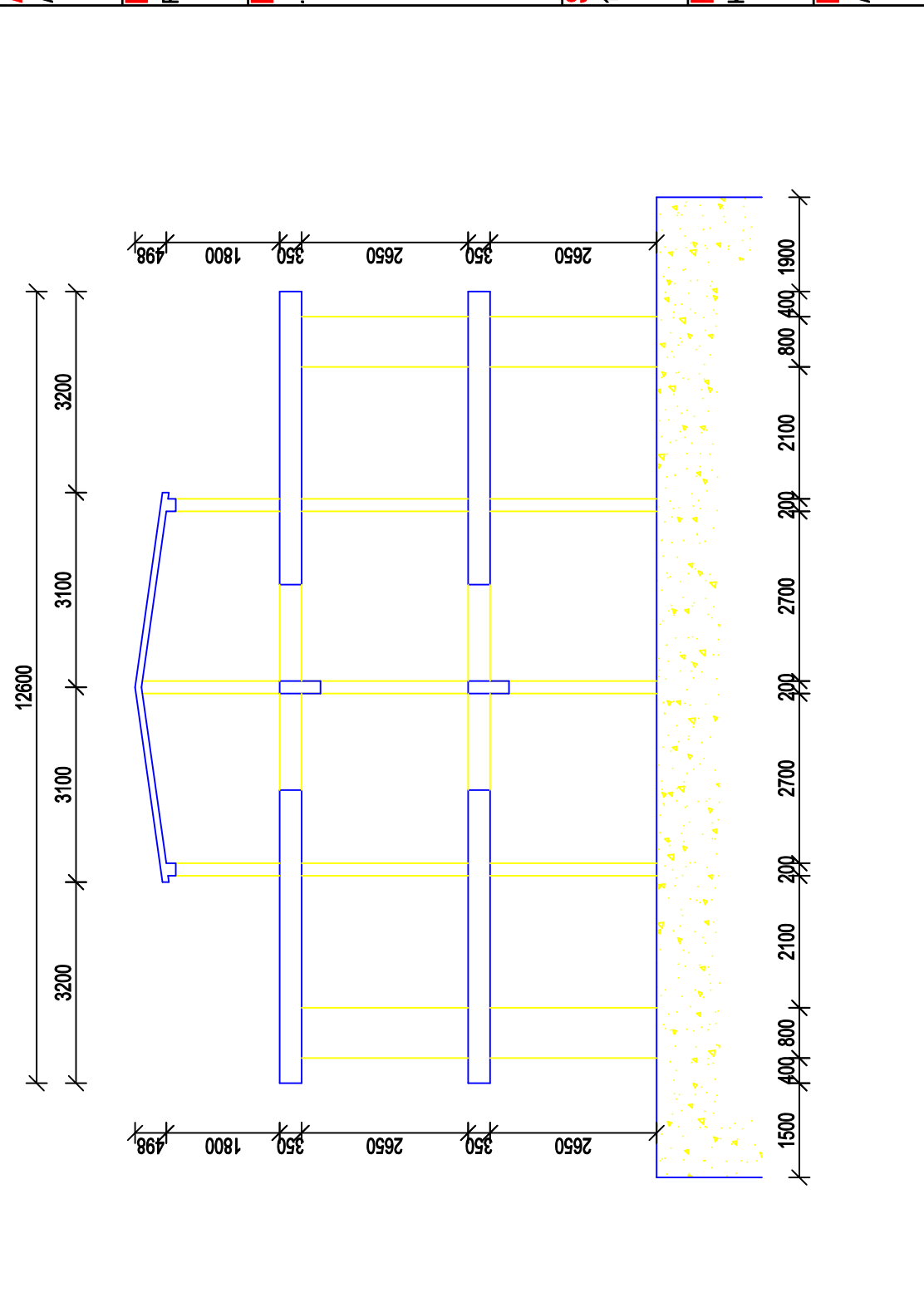
Appendix 2: As-Built Data for the Case Study					
Materials Used: Reinforced Concrete					
Notes: ...					
Scale in A4: 1/100					
Project Name: Kusadasi Summerhouse					
Drawing Name: First Floor Structure					

Appendix 2: As-Built Data for the Case Study					
Materials Used: Reinforced Concrete					
Notes: ...					
Scale in A4: 1/100					
Project Name: Kusadasi Summerhouse					
Drawing Name: Second Floor Structure					

Appendix 2: As-Built Data for the Case Study				
Materials Used: Reinforced Concrete (Columns) 195mm Blocks (Walls)				
Notes: ...				
Scale in A4: 1/100				
Project Name: Kusadasi Summerhouse				
Drawing Name: Ground Floor Plan				

Appendix 2: As-Built Data for the Case Study				
Materials Used: Reinforced Concrete (Columns) 195mm Blocks (Walls)	Notes: ...			
Scale in A4: 1/100	Project Name: Kusadasi Summerhouse			
Drawing Name: First Floor Plan				

Appendix 2: As-Built Data for the Case Study					
Materials Used: Reinforced Concrete (Columns) 195mm Blocks (Walls)	Notes: ...				
Scale in A4: 1/100	Project Name: Kusadasi Summerhouse				
Drawing Name: Second Floor Plan					

Appendix 2: As-Built Data for the Case Study					
Materials Used: Reinforced Concrete					
Notes: ...					
Scale in A4: 1/100					
Project Name: Kusadasi Summerhouse					
Drawing Name: A-A Section (Structure Only)					

<p>Appendix 2: As-Built Data for the Case Study</p>					
<p>Materials Used: Reinforced Concrete (Columns) 195mm Blocks (Walls)</p>					
<p>Notes: ...</p>					
<p>Scale in A4: 1/100</p>					
<p>Project Name: Kusadasi Summerhouse</p>					
<p>Drawing Name: A-A Section (With Walls)</p>					

